# Improving Prediction Accuracy of Matrix Factorization Based Network Coordinate Systems

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## I. INTRODUCTION

Network Coordinate (NC) systems provide a lightweight and useful way for scalable Internet distance prediction. In an NC system, a set of coordinates is assigned to each host, based on which the distance (a.k.a., end-to-end round-trip time) between any two hosts can be calculated with a predefined distance function. For an N-host network, the NC system is able to predict the distances of all the  $N\times N$  host pairs with only O(N) measurement overhead. So far, NC systems serve as critical components in many large-scale Peer-to-Peer applications, e.g., application layer multicast and anycast, server selection, multi-player online games, Azureus BitTorrent, PeerWise Overlay, and compact routing.

Most of the existing NC systems use the Euclidean distance model. In this model, all the N hosts are embedded into d-dimensional Euclidean space  $R^d$  ( $d \ll N$ ). The Euclidean distance model is simple for the implementation of NC systems. However, the Euclidean distance based NC systems bear the assumption that the predicted distances among any three hosts satisfy the triangle inequality. Unfortunately, according to a number of literatures, Triangle Inequality Violation (TIV) persistently occurs in the real Internet. As a result, the Internet distance cannot be predicted accurately with Euclidean distance based NC systems.

To overcome the problem of TIV, matrix factorization (MF) based NC systems such as IDES [7], Phoenix [1] and DMF [5] have been developed. According to the simulation study in [5], although there is already no TIV constraint in both IDES and DMF, neither of them has better prediction accuracy than Vivaldi, the most widely used NC system. Phoenix introduces the concept of *weight* in the NC calculation to distinguish between the referred NCs with high errors and low errors. This approach better explores the advantage of the matrix factorization model and thus becomes the most accurate single-level NC system so far.

Two-level hierarchical NC is encouraging for improving the prediction accuracy of NC systems, for example, hierarchical GNP [9] and Pharos [2] use a two-level hierarchy to improve the prediction accuracy of the short links of GNP or Vivaldi. In this paper, we choose Phoenix NC as our basic reference NC algorithm since it is the most accurate single-level NC so far. After grouping all the hosts into different locality-based clusters, we employ an independent Phoenix NC algorithm for each cluster and find that the prediction accuracy of intra-

cluster links is substantially improved compared with relying on a global Phoenix NC algorithm. Based on this observation, we design an effective two-level hierarchical NC system, called Pancake. Pancake uses a lightweight and decentralized approach called binning to group all the hosts into different clusters. In each cluster, an independent local Phoenix NC algorithm is used to predict the distances of intra-cluster links. For the distances of inter-cluster links, Pancake still adopts the global Phoenix NC algorithm to do prediction. According to our extensive evaluation, compared with Phoenix, Pancake reduces the 90th percentile relative error (NPRE) by up to 25.37%. Compared with Vivaldi, the most widely used NC system, Pancake even reduces the NPRE by up to 45.65%. Compared with Pharos, another two-level NC system based on Vivaldi, Pancake reduces the NPRE by up to 31.51%. In addition, Pancake converges very fast and is robust to different values of dimensions.

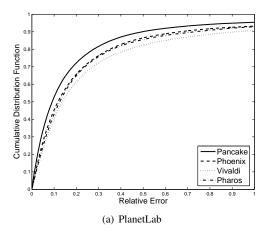
## II. EVALUATION

# A. Settings

In this section, we evaluate the performance of the Pancake NC system. In the perspective of relative error in distance prediction, Pancake is compared with three typical NC systems. One is Phoenix [1] which is the basic NC system for Pancake. Another one is Vivaldi [3], the most widely used NC system so far. There are some other 2-level hierarchical NC systems proposed in the literatures (e.g., Hybrid GNP [9], Pharos [2]). We do not evaluate Hybrid GNP [9] here since it is a centralized approach (the NC calculation of the whole system relies on a fixed set of landmarks), which cannot scale well. Consequently, it has never been used in any large scale Internet application. Pharos [2] is another two-level NC system which utilizes Vivaldi as its basic NC system in each level. It has been used as distance prediction module in Proxima [8], an application layer anycast system. We choose Pharos as the third NC system to compare with Pancake.

As in [1], we use the default parameters for Phoenix and Vivaldi. All the NC systems use 8-dimensional NC. In Phoenix and Pancake, a host measures 32 reference hosts in one update round. In both Pancake and Pharos, five randomly selected anchors are used. Ten independent runs are conducted on each data set and the average results are reported.

Our simulation is based on two widely used Internet distance data sets. Besides PlanetLab data set that mentioned above, we also use King data set. This data set is derived from



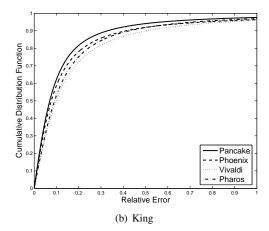


Fig. 1. CDF of Relative Error (Dimension = 8)

TABLE I 90th Relative Error (NPRE) of Pancake, Phoenix, Pharos and Vivaldi

NC System Data Set	Pancake	Phoenix	Vivaldi	Pharos
PlanetLab	0.50	0.67	0.92	0.73
King	0.33	0.41	0.50	0.44

the end-to-end RTTs among about 2000 Internet DNS servers, which are collected by the P2PSim project using King tool. As in [4], we remove partial measurements to derive a  $462 \times 462$  complete and square distance matrix.

# B. Relative Error of Distance Prediction

Fig. 1 shows the comparison among these four NC systems using the two representative data sets. According to the simulation results, we can find that Pancake achieves much higher prediction accuracy than other existing NC systems. Table I shows the NPRE values of the four NC systems on two different data sets. Compared with Phoenix, Pancake reduces the NPRE by between 19.51% (King data set) and 25.37% (PlanetLab data set). Compared with Pharos, Pancake reduces the NPRE by between 25.00% (King data set) and 31.51% (PlanetLab data set). Compared with Vivaldi, Pancake reduces the NPRE by between 34.00% (King data set) and 45.65% (PlanetLab data set). Therefore, Pancake improves the prediction accuracy of Phoenix even further.

### III. FUTURE WORK

Implementation and deployment on real Internet is the next step of Pancake. We are going to deploy Pancake on G-Lab [10] and PlanetLab. We can improve our design through real world evaluation. Also, we will integrate Pancake into a global application layer anycast system to serve as the basic distance prediction module for locality-aware Peer-to-Peer applications.

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