Nonlinear Modeling of the Internet Delay Structure

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ABSTRACT

Modeling the Internet delay structure is an important issue in designing large-scale distributed systems. However, linear models fail to characterize Triangle Inequality Violations (TIV), motivating us to research on nonlinear ones. In this paper, we propose the methodology and design of nonlinear modeling by utilizing Kernel Methods(KM), which is demonstrated effective by simulation. Moreover, our nonlinear model is easy to be applied without introducing any measurement overhead.

1. INTRODUCTION

Modeling the Internet delay structure[1] is crucial in designing large-scale distributed systems. The resulting model should 1) have a compact $O(N)$ representation compared to $O(N^2)$ matrix of the Internet delay structure; 2) maintain properties of Internet delay structure, especially Triangle Inequality Violations (TIV) which is reported in numerous studies[3]. Previous models mainly focus on Euclidean embeddings which are able to compact the matrix, but fail to characterize TIV. This failure of Euclidean embeddings reveals the inappropriateness of linear modeling of Internet delay structure, and hence provokes the advent of nonlinear modeling.

Kernel Methods (KM)[5] provide an approach to extend linear hypothesis to nonlinear ones which are popular in machine learning, including classification, regression and clustering. Our intuition is to introduce KM to the nonlinear modeling of the Internet delay structure.

In this paper, we firstly study the characteristics of TIV in Internet delay structure and then propose the concept of nonlinear modeling of Internet delays. We present the methodology and design of nonlinear models. The simulation results show that nonlinear models can better characterize TIV which will be beneficial to large-scale distributed systems. Moreover, our model is easy to be applied without introducing any measurement overhead.

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Table 1: 10%, median and 90% of cumulative distribution of TIV severity.

Data sets	10%	median	90%
PlanetLab	0	0.0029	0.0230
Meridian	0.0029	0.0925	0.7838

2. TIV IN INTERNET DELAY STRUCTURE

Triangle Inequality Violation (TIV) occurs in given nodes A, B and C, when $d(A, B) + d(B, C) < d(A, C)$, where $d(X, Y)$ denotes the measured delay between node X and Y. TIV highly degrades the performance of distributed systems which assume the triangle inequality holds, especially Euclidean systems.

On addressing TIV, several metrics[2, 3] have been proposed to characterize it. *TIV Ratio* is the number of triples of nodes violating triangle inequality to the proportion of all triples. *TIV severity* is defined in [3].

We investigate the characteristics of TIV in two different measured Internet delays data sets: PlanetLab(226 nodes) and Meridian(2500 nodes). TIV ratios of PlanetLab and Meridian are 0.2501 and 0.2350 respectively. Table.1 shows the TIV severity of the two data sets. We see through these data that there is considerable amount of TIV existing in the Internet.

3. NONLINEAR MODEL DESIGN

3.1 Modeling the Internet Delay Structure

In the model of the Internet delay structure, the input is measured Internet delays while the output is modeled Internet delays. A good model should compact the matrix of Internet delays as well as maintain its properties, such as TIV. To compact the matrix, each node is assigned a coordinate, which is updated by measured

Internet delays. The modeled Internet delays are represented by distances of the coordinates.

Several previous arts work on linear models, the representative one of which is Vivaldi[6]. However, they use Euclidean distances which holds the assumption of no TIV. This contravenes above analysis on the Internet delay structure. Thus we believe that the intrinsic model of the Internet delay structure is nonlinear.

3.2 Kernels

Kernel Methods (KM)[5] provide an approach to extend linear hypothesis to nonlinear ones. The kind of kernel K we will be interested in is *isotropic stationary kernel*[5]. For all examples $\vec{x}$ and $\vec{z}$ in an input structure $X \subset \mathbb{R}^d$, isotropic stationary kernel is defined as $K(\vec{x}, \vec{z}) = K_S(\|\vec{x} - \vec{z}\|)$. It depends only on the norm of the lag vector between $\vec{x}$ and $\vec{z}$. Euclidean norms can be viewed as such kernel, when $K(\vec{x}, \vec{z}) = \|\vec{x} - \vec{z}\|$. Our intuition is to extend Euclidean norms to other isotropic stationary kernels.

3.3 Methodology

The challenge is how to achieve the appropriate isotropic stationary kernels. To address this, our methodology is based on the following assumption. If there exists K_S^{-1}, we map the measured Internet delay matrix D_{MS} into another space to form a new matrix D_K such that $D_K = K_S^{-1}(D_{MS})$. A D_K with less TIV approximately reflects a better kernel, since Euclidean models can be embedded in D_K without TIV problem.

As an early work, we only study the polynomial kernel which is defined as $K(\vec{x}, \vec{z}) = \|\vec{x} - \vec{z}\|^2$. TIV ratio of D_K by polynomial kernel for PlanetLab and Meridian is 0.0017 and 0.0287 respectively. In this way, TIV is alleviated in D_K compared with in D_{MS}. Thus, linear models can be better embedded in D_K.

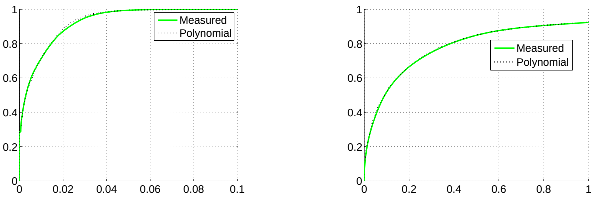
3.4 Modeling Framework

The framework of nonlinear modeling of the Internet delay structure is comprised of three steps. **Step1.** Map matrix D_{MS} into matrix D_K such that $D_K = K_S^{-1}(D_{MS})$. **Step2.** Conduct Vivaldi to compute the modeled matrix D'_K. **Step3.** Map matrix D'_K into matrix D_{MD} such that $D_{MD} = K_S(D'_K)$. The nonlinear model can be easily realized without introducing any measurement overhead.

Moreover, Vivaldi is only an example of computing the modeled Internet delays and can be replaced by any other example capable of realizing the same function.

4. EVALUATING THE MODELS

We evaluate TIV ratio and TIV severity of D_{MD}. The implementation of Vivaldi follows [4]. Parameters of Vivaldi are set to 10D, random neighbors and 5000 rounds while other parameters as indicated in [6]. The TIV ratios of modeled PlanetLab and Meridian data are 0.2745 and 0.2557 respectively, which resemble their counterparts in measured data. This is a great improvement compared to the zero TIV ratios of linear models. TIV severity of modeled Internet delays is as Fig.1. While TIV severities of all edges in linear models are all zero, TIV severities in our nonlinear model are almost equivalent to measured Internet delay structure in both PlanetLab and Meridian data sets. The improvement in the two metrics indicate that our nonlinear model can better characterize Internet delay structure compared to linear ones. In addition, the results demonstrate the assumption of "less TIV in D_K, better kernel".



(a) PlanetLab-226 (b) Meridian-2500

Figure 1: Cumulative distribution of TIV severity in PlanetLab and Meridian data sets

5. CONCLUSION

In future work, we plan to study more kernels presented in [5] to better fit the Internet delay structure. We will also study the measurement and methodology on how kernels benefit the characterization of Internet delay structure.

6. REFERENCES

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