Degrees Reconfiguration of Virtual Network Topology based on Traffic Matrices

S.Suresh
Department of Computer Science and
Engineering/Adhiyamaan College of Engineering,
Hosur-635109, India.

Renukadevi S
Department of Computer Science and
Engineering/Adhiyamaan College of Engineering,
Hosur- 635109, India.

ABSTRACT

In entire network data is transmitted from source to destination by VNT. Dynamic virtual network topology(VNT) reconfiguration method for internet protocol over tomogravity method under traffic matrix. While transmission the traffic will occur to reach the destination. These traffic matrix include the estimation errors. Estimation can be measure by load in each link. Estimation errors will degrade the performance of traffic engineering. A traffic matrix is required to design, plan, and manage telecommunication network. Instead of doing VNT reconfiguration at once have to divide VNT reconfiguration at multiple stages. By dividing, the error can be reduced at each stage.

General Terms

Design, Measurement, performance

Keywords

Internet Protocol(IP), Traffic matrix, Virtual network topology(VNT), Link loads, Traffic engineering

1. INTRODUCTION

Traffic matrix is very important for network operators. Traffic engineering is a representation of a method of optimizing the performance of telecommunication network and regulating the behavior of data transmitted over that network. The application include logical topology design, planning and managing configuration. Traffic matrix is collected by data collection. Traffic matrix conduct traffic engineering task. IP network is made up of IP routers, within single system. Networks consist of set of nodes, links, routers and adjacencies. The volume of traffic T i,j from i to j is time interval. Tomogravity method is simple, efficient,accurate for IP network traffic matrix estimation. The method have an ideas from gravity modeling and tomographic methods.Tomografic method based on the system of linear equation.

$$X=At$$

where **t** is the traffic matrix (written as a column vector), **X** represents link loads, and **A** the network routing matrix. The equation statesthat the traffic matrix must be consistent with network routing and measured link loads throughout the network, not just at the edge.

2. RELATED WORK

2.1 Virtual Network Topology (VNT)

It consists of electrical IP router part and optical cross-connect (OXC) part is used to connect. Every port of electrical IP router is connected to the OXC port via internal fiber. All traffic between nodes is carried over the link load. A lightpath is established between nodes by setting up the crossconnects along the route between nodes. The number of wavelengths per link and the number of transceiver port per node is a limited resource in determining the VNT.

2.1.1 Virtual Topology Reconfiguration

A major advantage of an optical network is that it may be able to reconfigure its virtual topology to adapt to changing traffic patterns. Some reconfiguration studies on optical networks have been reported before however, these studies assumed that the new virtual topology *was known a priori*, and were concerned with the cost and sequence of branch-exchange operations to transform from the original virtual topology to the new virtual topology. We propose a methodology to *obtain the new virtual topology*, based on optimizing a given objective function, as well as minimizing the changes required to obtain the new virtual topology from the current virtual topology. This approach would result in the minimum number of switch retunings, thus minimizing the number of disrupted lightpaths. Consequently, this approach also minimizes the time it takes to complete the reconfiguration process. Some discussions on the control mechanisms required to perform retuning of lightpaths. The ILP formulation in Section II can help us derive new virtual topologies from existing virtual topologies. In the ideal situation,
given a small change in the traffic matrix, we would prefer for the new virtual topology to be largely similar to the previous virtual topology, in terms of the constituent lightpaths and the routes for these lightpaths, i.e., we would prefer to minimize the
changes in the number of WRS configurations needed to adapt from the existing virtual topology to the new virtual topology. Given a certain traffic matrix, there may be many different virtual topologies, each of which has the same optimal value with regard to the objective function, i.e., (2). Usually, an optimizaton package will terminate after it has found the first such optimal solution.

2.2 Design Goal

First, the method should be simple. Simple method means quick responsiveness and easy to implement. Second, the method should be efficient. The goal of traffic engineering is to optimize network resource utilization. Third, the method should work as a distributed system to achieve robustness against failure. It works automatically with minimum human intervention.

The first issue stems from the fact that the different virtual network topologies are obtained if we change the order of lightpath setup/teardown. If two nodes assume different order of lightpath setup/teardown, they have inconsistent views of the new VNT. The second issue stems from the fact that one node may request to tear down an underutilized lightpath while the other may maintain it for quality-of-service (QoS) concerns . Two issues need to be addressed in designing the distributed method for the VNT reconfiguration. The first one is the order of lightpath setup and/or teardown and the second one is the conflicting requests on lighpath.

2.3 Control Mechanism

Each node in the network initiates the VNT reconfiguration procedure. The link-state routing protocol is used to flood information on the VNT and traffic demand over the lightpath throughout all nodes in the networks. The VNT is reconfigured after each node finishes setting up and tearing down the lighpaths. Once the new VNT is achieved, the IP traffic is rerouted over the new VNT. The distributed method is extending a link-state protocol. All link-states in the network need to be shared by all nodes. The larger the network size, the larger the number of link-states. For a large scale network, a hierarchy could be used to achieve scalability. On the other hand, the network utilization could be compromised due to suboptimality of hierarchical approach.

2.4 Multi-stage Heuristic Reconfiguration Approach

In a virtual topology designed for a particular traffic, if node pairs with high traffic were far apart in the virtual topology in terms of the number of hops, the routed traffic would increase greatly, and the load on links in the virtual topology would increase also. Intuitively, it can be seen that reconfiguration should establish lightpath between node pairs that have large traffic in order to reduce the routed traffic and hence the average weighted hop count.

Heuristic approaches have the inherent drawback of continual approximation. This may lead to an increase or decrease in the difference between the theoretical optimal solution and the current solution, as approximations are applied every time. Whether the difference increases or decreases is very difficult to determined. To take care of this, traffic prediction is introduced to compensate for this continual approximation in this study. In this section, we present a heuristic algorithm that realizes the multi-stage decision-making process, which tries to counter the continual approximation by using predicted traffic.

Heuristics become important when the problem formulation becomes large due to increase in the physical size of the network, and becomes difficult to solve by traditional LP methods due to computational constraints. Results of these heuristics compare favorably with the optimal result obtained by solving the exact problem formulation. The details of optical layer path addition/deletion phases are as follows.

2.4.1 Optical Layer Path Addition Phase

If the utilization of an optical layer path exceeds , a new optical layer path is set up to reroute traffic away from the *congested* optical layer path. First, we collect a set of packet layer paths that pass the most congested optical layer path. Then, we select the busiest of the collected packet layer paths. Finally, we add the direct optical layer path (i.e., a single directly connected link) from ingress to egress nodes of the selected packet layer path.

2.4.2 Optical Layer Path Deletion Phase

If the utilization of an optical layer path is less than and the deletion of the optical layer path is shown not to cause congestion, the path is torn down so the IP router ports and wavelengths can be reclaimed for future use. The optical layer path is checked for potential for its deletion to cause congestion by calculating the utilization of optical layer paths after deletion using the traffic matrix estimated in the current stage. If there is more than one candidate for deletion, each candidate path is tested in ascending order of utilization.

2.5 Heuristic Algorithm for VNT Calculation

A heuristic algorithm is used for calculating the VNT because it is simple enough to work quickly. In order to make the method work in a distributed manner, we do not assume any order of setup/teardown of lightpaths in designing the VNT calculation algorithm. The algorithm adds new lightpaths to mitigate congestion and removes existing underutilized lightpaths if possible for eclamation. The VNT algorithm should not assume any order of setup/teardown of lightpaths initiated by individual originating nodes. Multiple new lightpaths may contend the same resource of the number of wavelength links and the number of transceiver ports before all underutilized lightpath candidates are removed. To avoid this situation, the heuristic algorithm adds new lightpath candidates first without relying on resources returned by removed lightpaths, and then removes existing nderutilized lightpaths.

All underutilized lightpaths are tested in a deterministic order in calculating the new VNT.We should note that even though we assume the deterministic order of lightpath deletion in the VNT calculation, we do not have to care about the order of lightpath teardown after the new VNT is determined.

2.6 Network Model

We consider a network of nodes connected by bidirectional optical links forming an arbitrary physical topology. Each optical link supports wavelengths, and any node is assumed to have transmitters and receivers. We assume that each node is equipped with an OXC with full wavelength-conversion capability, so that a lightpath can be established between any node pair if the resources (an optical transmitter at source, an optical receiver at destination, and at least a wavelength on each fiber link) are available along the path. Mechanisms to accommodate no wavelength conversion and different numbers of wavelengths on different links are straightforward.We consider unidirectional lightpaths, since the traffic between two nodes is not necessarily symmetric.

Each OXC is connected to an edge device, e.g., an IP router, which can be a source or a destination of a traffic flow and which can provide routing for multihop traffic passing by that node. We assume that each router is capable of processing all packet traffic flowing through it and of observing the amount of traffic on its outgoing lightpaths. In this paper, for ease of explanation, we consider a centralized approach to the virtual topology reconfiguration problem. A central manager will collect the virtual-link usage information from routers at the end of every observation period. Specifically, the link-usage information needed to make a reconfiguration decision consists of which links are overloaded, which links are underloaded, and what are the end-to-end packet-traffic intensities flowing through the overloaded links. The decision for a topology change will then be made by the central manager, and a signaling mechanism will be started if a lightpath addition or deletion is required as a result of the decision algorithm (in this paper, for simplicity, we ignore the details of the signaling protocol). An implicit assumption here is that the observation period is much longer (typically hundreds of seconds or longer) than the time it takes for control signals to propagate from various nodes to the central manager. We expect that it is possible to design a decentralized protocol to do this job as well, but this is outside the scope of our present investigation.

In the optical layer, we use shortest path routing for routing lightpaths on the physical topology and the first-fit scheme for wavelength assignment. For packet routing, we consider a shortest path (minimum-hop) routing scheme, since it provides better usage of network links and is frequently used by existing routing protocols.

3. OVERVIEW OF PROPOSED METHOD

These methods differ in how they deal with the under-determination of the system of tomographic constraint equations. Optimization-based tomography approaches typically find a solution that optimizes an objective function, whereas network tomography approaches often use the higher order statistics of the link load data to create additional constraints. This system is highly under-constrained, and so the challenge is to choose the “best” solution from the space of possibilities. The typical approach has been to use additional modeling assumption to derive constraints from the higher order statistics of the traffic. An alternative that is well known in social sciences for modeling commodity exchanges is the gravity model. In network applications, gravity models have been used to model mobility in wireless networks, and the volume of telephone calls in a network. The paper also suggests using their method to generate priors to serve as inputs to statistical tomography techniques, but does not test this idea. An alternative generalization of the gravity model that explicitly models inter-peer routing was used. Gravity models are typically based on edge data, and as such do not guarantee consistency with the observed link loads on the interior of the network.

3.1 Background

3.1.1 Network

An IP network is made up of IP routers and IP adjacencies between those routers, within a single autonomous system or administrative domain. It is natural to think of the network as a set of nodes and links, associated with the routers and adjacencies. Network as backbone nodes and links, and refer to the others as edge nodes and links. In general the network will connect to other autonomous systems and customers via edge links. The edge links into access links, connecting customers, and peering links, which connect other (non-customer) autonomous systems. In large IP networks, distributed routing protocols are used to build the forwarding tables within each router. It is possible to predict the results of these distributed computations, from data gathered from router configuration files.

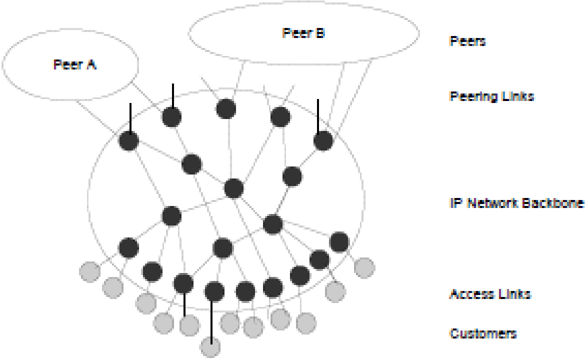

Figure 1. **IP network components and terminology**

3.1.2 Traffic Data

In IP networks today, link load measurements are readily available via the Simple Network Management Protocol (SNMP). SNMP is unique in that it is supported by essentially every device in an IP network. Since every router maintains a cyclic counter of the number of bytes transmitted and received on each of its interfaces, we can obtain basic traffic statistics for the entire network with little additional infrastructure support.

The properties of data gathered via SNMP are important for implementation of a useful algorithm – SNMP data has many limitations. Data may be lost in transit (SNMP uses unreliable UDP transport; copying to our research archive may introduce loss). Data may be incorrect (through poor router vendor implementations). The sampling interval is coarse (in our case 5 minutes). Many of the typical problems in SNMP data may be removed with minimal artifacts using simple techniques. Slightly more sophisticated methods of anomaly detection and interpolation produce even better results, but we shall use simple hourly data for the purposes of this study, as hourly (or longer) data are commonly dealt with by many ISPs. This data is collected at the router which aggregates traffic by IP source and destination address, and TCP port numbers.

Traffic matrix (TM) is a representation of the volume of traffic that flows between origin-destination (OD) node pairs in a communication network. Obtaining accurate TMs is very important for network operators that conduct traffic engineering tasks. Such measurements typically require specialized router software and hardware dedicated to data collection. The state-of-the-art research efforts in traffic matrix estimation have been focused on the modeling method, which relies on statistical inference techniques.

3.1.3 Traffic Dynamics

To understand traffic dynamics and what this may mean for OD traffic models, begin by some exploratory analysis of our traffic matrix data. Our data includes one month of OD pair measurements collected in Sprint's IP backbone network by enabling Netflow on all the incoming links from gateway routers to backbone routers. The resulting link-by-link traffic matrix is aggregated to form both a router-to-router and a POP-to- POP traffic matrix. Other traffic matrix studies have argued that the little flows (and errors in estimating them) can be ignored because network administrators only care about estimating the large flows correctly. The very small flows are not important because capacity planning tasks, route selection, load balancing, failure provisioning should be tailored to work for the vast majority of the traffic.

3.1.4 Terminology

For the purpose of computing traffic matrices, without loss of generality, assume that all access and peering links terminate at Edge Routers and that all remaining routers are Backbone Routers that only terminate backbone links. There may be more than one route between two routers even using only shortest paths. Assume that traffic will be evenly distributed across all such routes. One could compute traffic matrices with different levels of aggregation at the source and destination endpoints, for instance, at the level of PoP to PoP, or router to router, or link to link. Primarily interested in computing router to router traffic matrices, which are appropriate for a number of network and

traffic engineering applications, and can be used to construct more highly aggregated traffic matrices (e.g. PoP to PoP) using routing information.

3.2 Load Balancing

The adaptation mechanism works to balance the lightpath loads all over the network to maintain all loads in the balance region. In this section, we show the load-balancing ability of the system. Fig. 15 plots the distribution of lightpaths according to their loads, for three different watermark-value pairs. At the end of each observation period (300 s for this example), the loads of all lightpaths in the network are measured and the occurrence of each load is added to the total occurrences of that load since the beginning of the simulation. This process is repeated at the end of every observation period throughout the simulation. A point in this graphic indicates the percentage of the lightpaths with that load in the course of the experiment (a five-day run). The figure shows that a high percentage of the links are in the balance region. Another result is that most of the lightpaths are gathered in a smaller region toward the middle of the balance region, showing that fewlightpaths are critically close to thewatermarks, and they can trigger a topology adjustment in the observation period.

3.2.1 Load Minimization Solution

A unique feature of the placement problem for a synthetic traffic matrix is that link loads are unknown. This implies that the choice of how to organize the flow rates into a traffic matrix is impacted by both feasibility and congestion concerns. A particular placement is considered feasible if none of the link capacities are exceeded. In other words, by an appropriate choice of a traffic matrix and routing, one can minimize congestion (note that the matrix may not be feasible. We address this issue in a subsequent section.) Minimizing congestion is a desirable and widely used metric for traffic engineering. Hence, our first method, the Load Minimization Solution, seeks to determine a mapping that tries to achieve this goal. Our ILP solution will find a solution that meets the capacity constraints if such a solution exists; this partly comes as a consequence of minimizing congestion. For ease of exposition, we define some terminology below, before presenting the ILP.

3.3 Errors in Traffic Matrix Estimates

A detailed general analysis of the errors in the different traffic matrix estimates is presented in [4]. For reference in this paper we provide some simple measurements of the errors. we present relative error of estimated traffic matrices versus true traffic matrices. That is, for each hour we compute the sum (over the source-destination pairs) of the absolute value of the error between estimated and true traffic, and divide this sum by the total traffic. We see that tom gravity is more than twice as good as general gravity, which is more than twice as good as simple gravity. These findings are consistent with those reported in [4]. we present an alternative representation of the estimates more comparable with later figures on max-utilization.A simple-minded hypothesis is that optimizing over the true traffic matrix, the max-utilization is going to be proportional to mean traffic and that if we optimize over an estimated traffic matrix, the performance is degraded by mean error.The mean traffic plus the mean (absolute) errors for each of the data sets over the course of the day. If our simple-minded hypothesis is true, the curves should roughly match those of max-utilization achieved with the estimated traffic matrices.

3.3.1 Measuring Traffic Matrix Variation

Studying the variation of traffic matrix elements over time requires collecting finegrained measurements of traffic and routing. We collect data from eight aggregation routers that receive traffic from customers destined to peers and other customers. The eight routers are located in major Points of Presence (PoPs) that are spread throughout the United States. We compute eight *rows* of the traffic matrix, considering all traffic from these eight ingress aggregation routers to all of the egress PoPs.

3.3.2 Estimating Traffic Matrices From Link Data

This section describes three methods for estimating traffic matrices from link load data. The first two methods are based on so called "Gravity models" while the third uses (in addition) "Network tomography" methods. Although it might be appealing to test some more complex algorithms, the sub-sample of possibilities presented here is sufficient to illustrate the points of interest. What's more we find a near optimal combination of estimation and routing optimization algorithms in any case, so there is little to be gained in using a more complex method. This section is not intended to provide a detailed description of the estimator algorithms (which may be found in [4]). This is not intended as a study of the estimators. The novel aspect is what happens when the estimators are combined with routing optimizers and tested on real traffic matrices. The description here is to provide some insight into the relationship between the three algorithms tested. Gravity models, are often used by social scientists to model the movement of people, goods or information between geographic areas. Recently, variations on gravity models have also been proposed for computing traffic matrices. At the heart of the gravity model approach is a proportionality assumption: the amount of traffic from a given source to a given sink is proportional to the total traffic to the output sink, independent of source. For example, in a gravity model for car traffic between cities the relative strength of the interaction between two cities might be modeled as proportional to the product of the populations divided by a distance related "friction" term. Similarly, the simplest possible gravity models for the Internet assume that the traffic exchanged between locations is proportional to the volumes entering and exiting at those locations, though in this case we assume the distance related term is a constant because interactions in the Internet are less distance sensitive. This simple model of the Internet is used in , and we refer to it as the *simple gravitymodel*.

In practice this set of equations is ill-posed, and so to deal with this difficulty tomographic techniques from other fields have been used. For a detailed description and comparison (using simple metrics) of a number of these methods. We shall consider a single such algorithm, *tomogravity*, [2] which displays good properties in terms of scaling, estimation accuracy, speed of computation, and robustness to errors. The method uses the generalized gravity model above as a prior (a kicking off point) and refines it using a tomographic technique to select an estimate of the traffic matrix, that satisfies the constraint equations, but that is closest to the gravity model according to some distance metric.

4. SIMULATION AND COMPARISON

The node numbers (i and j) actually represent the size of the total flows generated from a node so that the volume of flow between these two nodes is decided by multiplying the node numbers of two nodes. A large flow exists between higher numbered nodes but these flows are scaled with a random factor based on a standard probability distribution. The mean of the Poisson distribution was 10 (λ) and the uniform random numbers are generated in the interval . These values have been chosen to ensure that both distributions have the same mean and variance.

4.1 Comparison And Discussion

The process for the TomoKruithof method is the same as that for the Tomogravity model - except that there are two more refining steps before and after the least square method has been applied. Then, the Kruithof method was applied to balance the initial matrix with the measured row and column sums. The TomoKruithof method uses one more constraint than the Tomogravity method. This means that the method may be more sensitive in terms of link load measurements. In a real network, it is hard to obtain accurate link loads because of limitations with SNMP. It is uncertain as to how much accurately link loads can be determined in a real backbone network.

4.2 Methods

We highlight three key aspects of each method: the type of OD flow model used, the type of data (or side information) brought in to calibrate the model, and the method of estimation. Focusing on these three aspects of each method is helpful in understanding the differences and similarities between various methods without getting lost in the details. We classify each model as being either spatial, temporal or spatio-temporal. A spatial model is one that captures dependencies among OD flows, but has no memory. In temporal models an OD flow model is dependent on its past behavior, but independent of other OD flows. Spatial models thus capture correlations across OD flows, while temporal models capture correlations in time. Clearly, spatio-temporal models are those that incorporate both types of correlation. The three third-generation methods presented here use different underlying OD flow models. The common feature of these methods is that they rely on data from flow monitors to calibrate their models. All of these methods assume that flow monitors are initially turned on network-wide for a period of 24 hours for initial model calibration. The flow monitors can then be turned off until further notice. All of these methods include simple schemes for change detection, and when changes are detected, flow monitors are turned back on for another period of 24 hours. Our validation data had an estimate of the traffic matrix at each 10 minute time interval. Hence all methods estimate the traffic matrix on a time scale of 10 minutes (the underlying time unit *t*).

4.3 Solution

Term tomogravity indicates, the method consists of two basic steps – a gravity modeling, and a tomographic *estimation.*

4.3.1 Gravity Modeling

Gravity models, taking their name from Newton's law of gravitation, are commonly used by social scientists to model the movement of people, goods or information between geographic areas. In Newton's law of gravitation the force is proportional to the product of the masses of the two objects divided by the distance squared. Similarly, in gravity models for cities, the relative strength of the interaction between two cities might be modeled as proportional to the product of the populations. assume a common constant for the friction factors, which is arguably the simplest among all possible approximation schemes. The resulting gravity model simply states that the traffic exchanged between locations is proportional to the volumes entering and exiting at those locations. As long as the gravity model captures the essence of the routing policies comes very accurate and the choice of the friction factors is less critical. do not expect our gravity model to accurately model the traffic between all source-destination pairs. In fact, one would acturally expect certain pairs of locations to stand out from the overall distribution, simply due to their specific characteristics. A key insight of the tomogravity method is that we only need the gravity model to capture the overall distribution. It is certainly possible to further improve the method by using more accurate gravity models with additional parameters. The margin for improvement may be limited.

Another important issue concerning the gravity model is the level of aggregation. The aggregation level to be sufficiently high so that the traffic exchanged between different locations is not sensitive to the detailed composition of the traffic. On the other hand, when the aggregation level is too high.

4.4 Tomography

Network tomography, as mentioned earlier, is the problem of determining the end-to-end traffic matrix from link loads. The link traffic is the sum of the traffic matrix elements that are routed across that link. For general topologies and routing there are typically many more unknowns than constraints, does not have a unique solution. Approach is not to incorporate additional constraints, but rather to use the gravity model to obtain an initial estimate of the solution, which needs to be refined to satisfy the constraints. it is important to reduce the size of the problem to make computation of the solution more manageable.

4.4.1 Tomogravity Accuracy

The constraints may not be satisfiable due to error and noise in the link load data or possible routing changes that are not captured by the topology data. The standard technique for dealing with ill-posed quadratic programs is to use Singular-Value Decomposition (SVD) of the routing matrix _ to compute its pseudo-inverse. The worst case complexity of the above algorithm is linear in the number of unknowns elements of the traffic matrix), and quadratic in the number of constraints, however, in practice the complexity of singular value decomposition methods is generally less than this. One additional locus of complexity is that the least-square algorithm may result in negative values, which are without physical meaning. One can avoid this by viewing the problem as a constrained optimization problem. However, a simple iterative procedure provides a fast and effective alternative. In practice it only takes a few iterations to reduce errors in the constraint equations to the point at which they are negligible.

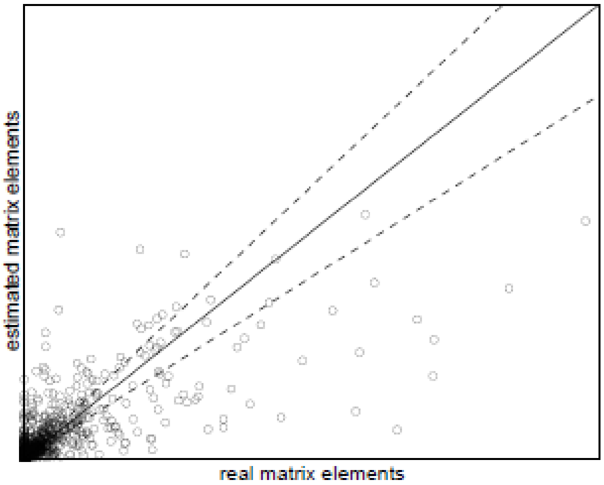

Figure 2. **Simple gravity model**

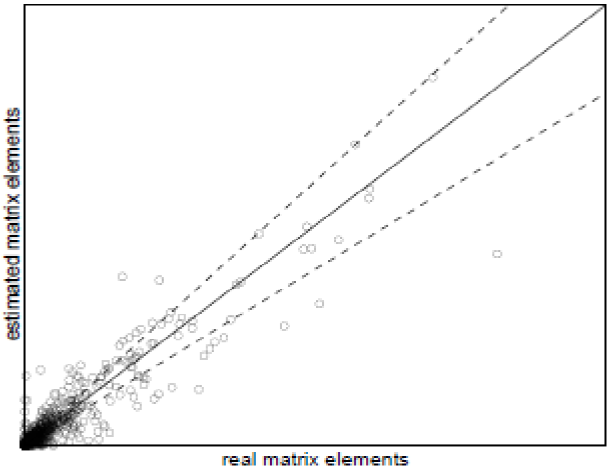

Figure 3. **Generalized gravity model**

4.4.2 Methods

Tomographic methods have been widely and successfully applied, for example, in Computer Aided Tomography (CAT) scans, used in medical imaging. These methods differ in how they deal with the under-determination of the system of tomographic constraint equations.Optimization-based tomography approaches typically find a solution that optimizes an objective function, whereas network tomography approaches often use the higher order statistics of the link load data to create additional constraints. Network tomography, in some sense, comprises determining the solution to equation, or at least the parameters of some model of , from measurements of x . As noted above, this system is highly under-constrained, and so the challenge is to choose the "best" solution from the space of possibilities. The typical approach has been to use additional modeling assumption to derive constraints from the higher order statistics of the traffic. The paper also suggests using their method to generate priors to serve as inputs to statistical tomography techniques, but does not test this idea.

REFERENCES

[1] A. Feldmann, A. Greenberg, C. Lund, N. Reingold, J. Rexford, and F. True, "Deriving traffic demands for operational ip networks: methodology and experience," *In Proc. ACM SIGCOMM*, Aug 2000.

[2] Y. Vardi, "Network tomography: Estimating source-destination traffic intensities from link data," *J. Amer Stat Assoc*, pp. 365–377, 1996.

[3] D. Lam, D. Cox, and J. Widom, "Teletraffic modeling for personal communications services," *IEEE Communications Magazine: Special Issues on Teletraffic Modeling Engineering and Management in Wireless and Broadband Networks*, 35, pp. 79–87, February 1997.

[4] J. Kowalski and B. Warfield, "Modeling traffic demand between nodes in a telecommunications network," in *ATNAC'95*, 1995.

[5] L. Zhang, K. Lee, and C.-H. Youn, "Adaptive virtual topology reconfiguration policy employing multi-stage traffic prediction in optical Internet," in *Proc. Workshop High Perform. Switching Routing*, May 2002, pp. 26–29.

[6] K. Shiomoto, E. Oki, W. Imajuku, S. Okamoto, and N. Yamanaka, "Distributed virtual network topology control mechanism in GMPLSbased multiregion networks," *IEEE J. Sel. Areas Commun.*, vol. 21, no. 8, pp. 1254–1262, Oct. 2003.

[7] A. Gencata and B. Mukherjee, "Virtual-topology adaptation for WDM mesh networks under dynamic traffic," *IEEE/ACM Trans. Netw.*, vol.11, no. 5, pp. 236–247, Oct. 2003.

[8] B. Mukherjee, D. Banerjee, S. Ramamurthy, and A. Mukherjee, "Some principles for designing a wide-area WDM optical network," IEEE/ACM Trans. Netw., vol. 4, no. 5, pp. 684–696, Oct. 1996.

[9] C. Tebaldi and M. West, "Bayesian inference on network traffic using link count data," *J. Amer. Statist. Assoc*, 93, pp. 557–576, 1998.

[10] J. Cao, D. Davis, S. V. Wiel, and B. Yu, "Time-varying network tomography," *J. Amer. Statist. Assoc*, 95, pp. 1063–1075, 2000.

[11] A. Adams, T. Bu, R. C´aceres, N. Duffield, T. Friedman, J. Horowitz, F. L. Presti, S. Moon, V. Paxson, and D. Towsley, "The use of end-to-end multicast measurements for characterizing internal network behavior," *IEEE Communications Magazine*, May 2000.

[12] M. Coates, A. Hero, R. Nowak, and B. Yu, "Internet tomography," *IEEE Signal Processing Magazine*, May 2002.