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Robust Routing

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Abstract

In a network, traffic demands are known with a degree of uncertainty, traffic engineering should take into account the traffic variability. In this research work we focus on the robust routing under changing network conditions. Daily internet traffic pattern shows that network is vulnerable to malicious attacks, denial of service attacks, worms and viruses. Oblivious routing has a substantially better performance than Open Shortest Path First [OSPF] routing for different level of uncertainty. We propose a theoretical framework for Robust Routing aiming to improve online and offline traffic engineering approaches.

Keywords

Robust Routing, Traffic Matrix, Oblivious Routing.

1. Introduction

Internet applications such as voice-over-IP, video-on-demand and peer-to-peer are characterized as having unpredictable traffic pattern. Classical approaches are based on modeling traffic as a single or multiple traffic metrics for the design and dimensioning of the network. When actual traffic does not come in line with such modeling, desired Quality of Service (QoS) cannot be guaranteed due to network congestion. Development of routing infrastructures that can optimize network resources while accommodating traffic uncertainty in a robust and efficient manner is one of the open and potential research areas for the next generation Internet.

Routing Optimization refers to finding set of paths between pair of origin and destination routers by optimizing an objective function subjected to traffic demand and capacity constraints. Relying on precise knowledge of the Traffic Matrix (TM) may enable optimal solutions. However in practice, traffic demand between each node pair changes.

Traffic Engineering (TE) scheme based on distributed load based update [8] and on-line monitoring [13] that uses precise knowledge of traffic can lead to network instability and complexity. Prediction based TE algorithms provide routing optimization for collected samples from a stable traffic without preparing for unpredictable traffic spikes. Online approach is an extreme case of prediction-based TE.

Traffic Engineering is now playing a vital role for network design and dimensioning. Traffic engineering algorithms largely depends on the traffic pattern. Traffic demand is usually stable most of the time but there exits time period when it is highly dynamic and unpredictable. Traffic traces of several backbone networks [2] indicate that traffic demand vary during this period. Highly unpredictable traffic variations have been studied recently by other researchers [10, 11, 12 and 13].Unpredictable traffic is the result of the factors e.g. Denial of Service attacks, intradomain routing changes of major ISPs and outbreaks of worms and viruses.

Data networks in practice follow the OSPF policy: where arc weights are used to select the shortest path in the route selection between origin and destination. Routing optimization with OSPF thus consists of finding the value of weights so as to optimize some network performance measure [4, 17, and 18]. Other popular forwarding techniques such as Multi–Protocol Label Switching (MPLS) do not constraint route length, thus allowing multiple implementation of any routing.

The concept of oblivious routing aims at developing routing algorithm that base their routing decisions on local knowledge and therefore can be deployed very efficiently in a distributed environment. However, the traffic demand is seldom known with accuracy because of difficulty in measurement or due to variation.

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The uncertainty in the traffic leads us to address some issues:
-Finding a robust routing strategy over a range of traffic demands.
-How traffic model can scale to the traffic variations.
-Optimizing the routing to provide cost effective services.

In this paper we are proposing routing algorithm to address robustness under changing traffic demand due to denial of service attacks and intradomain routing changes.

Paper is structured as follows: we presented related research work in this area in section 2 followed by preliminaries and notations in section 3. In section 4 we defined problem, its linear program formulation and solution approach. Computational experiments are briefly described in section 5.We present conclusion and future work in section 6.

2. Related Work

There are thee classes of solutions in this area of research:

1. Oblivious routing – [1], [6], [16].
2. Link weight optimization – [4], [17], [18].
3. Traffic engineering adaptive approaches – [7], [8].

In recent years a body of literature is developing in the area of robust routing optimization. In [1], Applegate and Cohen proposed a simple polynomial size LP to obtain a demand based oblivious routing scheme. They computed network performance and found performance ratio near 2 for changing traffic. A potential drawback of oblivious routing, however is its suboptimal performance for normal traffic. In [3], Azar et al. introduce the concept of oblivious routing. Their performance metric for a routing is relative and it does not give any guarantee about the absolute performance of the selected routing. Oblivious routing problem is to develop a routing that achieves a near optimal performance with little knowledge of TM.

Link weight optimization is based on adjusting weights for the routing decisions and guarantees performance over a limited set of traffic demands. An adaptive approach is responsive to the traffic changes, so that the issue of stability and convergence needs to be addressed both in theory and in practice. Oblivious routing aims for the optimal routing regardless of network demand assuming no knowledge of traffic matrix. In [4], Fortz and Thorup deployed a local search technique for OSPF/IS-IS to find a set of link weights which gives good performance for a given TM or a set of TMs. Advances in traffic measurement are proposed in [10, 11, 12, 13, 14, and 15].

More recently, there have been proposals for online Multipath traffic engineering [7, 8].They have both proposed a distributed adaptive traffic engineering algorithms, which may cause routing instability.

Common-case Optimization with Penalty Envelope (COPE) [6] is our inspiration for the research work. COPE propose a deterministic approach using a notion of penalty envelope and modeling traffic demand as a convex-hull. The convex-hull based TE is effective in situations when traffic demand fall into the convex hull.

In our case model is not trivial as we would have to make sure that all traffic flows through the network which in the deterministic case would mean taking the minimum capacity, but this would make little sense.

We are using a combined approach of [1] and [6] to find a polynomial size Linear Programming model with finite constraints for robust routing. This paper models traffic demand as a random variable (section 4.2). Daily traffic pattern shows us that while network can handle link cuts and router crashes, they remain vulnerable to more complex faults that include implementation bugs, configuration mistakes, malicious attacks and greedy users e.g. wide spread Internet service outages can be caused by denial of service attacks, worms and viruses. We are focusing on the problem of investigating routing robustness under changing network conditions due to malicious attacks and greedy users. Refer Table-1 for a brief overview of the related research work.

Algorithm	**No of TM**	**Constraints model**	**LP size**	**Routing formulation**
Applegate and Cohen	Infinite	Pipe	finite	Link Based
Azar et al.	Infinite	No constraints	Infinite	Link Based
Zhang et al	Finite	NA	Finite	Link Based
Ben-Ameur et al. [22]	Infinite	Hose and Pipe	Infinite	Path Based
Our approach	Finite	Hose and Pipe	Finite	Path based

Table 1. Related research work

3. Preliminaries and Notations

3.1 Traffic demand, Traffic Matrix and Routing

A traffic demand is defined as a tuple of origin router, destination router and the flow between these two routers.

The traffic demand originates from a client connected via the ISP through the origin router and is destined for a specific client at the destination router.

A traffic matrix is the amount of traffic between Origin-Destination (OD) pair over a certain time interval. It represents the traffic demand between every origin node i and every destination node j in the network and defined by the following constraint:

$$d_{ij} \geq 0$$

The routing refers to route traffic between each OD pair. Popular internet routing protocols are the OSPF and IS-IS. MPLS architecture allows a flexible forwarding paradigm. MPLS combined with OSPF or IS-IS can take advantage of the path diversity. Our work is mainly based on MPLS which is widely deployed by ISPs.

3.2 Performance Metrics

The most common performance metric of a given routing problem with respect to a certain Traffic Matrix (TM) is defined as the Maximum Link Utilization (MLU). This is the ratio of the maximum between the total flow and capacity over all the links [1].

The formal definition of the MLU of a routing f on TM D, where d_{xy} is the demand from the nodes x to y, is expressed as follows

$$\max_{(i,j)\in links} \sum_{x,y} \frac{d_{xy}.f_{xy}(i,j)}{cap_{ij}}$$

Where cap_{ij} is the capacity of the link *(i, j).*

An optimal routing solution for a certain TM D is the routing that reduces the MLU for TM D, and is defined in the following formula:

$$\text{OPT U (D)} = \min_{f|f \text{ is routing}} \max_{(i,j)\in links} \sum_{x,y} \frac{d_{xy}.f_{xy}(i,j)}{cap_{ij}}$$

The Performance Ratio is defined as the ratio of the MLU of “f” on D over the maximum number of the possible link utilization of the given TM.

$$PERF(f,\{D\}) = \frac{\max_{(i,j)\in links} \sum_{x,y} d_{xy} f_{xy}(i,j) / cap_{(i,j)}}{_{OPT}U(D)}$$

In addition, it should be noted that the optimal routing for a given range of TM can be solved as the Multi-Commodity Flow Linear Program. Since the traffic pattern is highly variable in its nature, it is not always possible to obtain accurate estimate of the current TM.

When the set *D* includes all possible TMs, we refer to the performance ratio as the oblivious performance ratio of a routing. The oblivious ratio is the worst performance ratio a routing obtains over all traffic matrices. A routing with the minimal oblivious ratio is an optimal oblivious routing and its oblivious ratio is the optimal oblivious ratio of the network.

3.3 Single Path and Multipath Routing

When a traffic demand can have a single path from its source to destination we have:

$r^e_{ij} \in (0, 1)$; $\forall (i, j) \in N \times N, \ \forall e \in E$

When traffic can have multiple paths from source to its destination, we have:

$0 < r^e_{ij} \leq 1$; $\forall (i, j) \in N \times N, \ \forall e \in E$

r^e_{ij} : Proportion of traffic demands going from node i to node j through edge e.

3.4 Capacity Constraint

The capacity constraint corresponds to the limitation of the total demands being routed across each edge being smaller or equal to the edge capacity i.e.:

$$\sum_{(i,j)\in NxN} r^e_{ij} \,.\, d_{ij} \leq cap_e \qquad \forall e \in E$$

The above capacity constraint can also be defined using a ratio variable. We denote σ_k as a variable to represent the ratio between sum of the demands routed through each edge and the capacity of edge.

$$\sum_{(i,j)\in NxN} r^e_{ij} \,.\, d_{ij} \leq \sigma_k \,.\, cap_e \qquad \forall e \in E$$

The value of this ratio variable may define congestion over the network. When σ_k is greater that 1, the network is congested.

4. Problem Definition and Solution approach

4.1 Problem definition

Our problem is a fundamental routing problem. Routing can be classified as a flow routing or destination based routing. In flow routing for each origin destination (OD) pair, router maintains a fraction of flow along the path. Routing fractions are useful for describing the set of routes along which packets are forwarded. We denote $r_{kl}(i,j)$ as the function of traffic originating from node i destined to node j at node k, forwarded over edge (k, l).In figure 1, node 3 forwards 10 units of traffic originating from node 1 destined to node 6 over edge (3, 4).Similarly 10 units originating from node 2 are forwarded to destination node 6 over edge (3, 5).On the other hand destination routing, shown in figure 2, maintains routing fraction for each destination. Specifically $r_{kl}(i,j)$ denotes the fraction of traffic flow destined to node j at node k forwarded over the outgoing edge (k, l). In short destination routing can be vied as a special case of flow routing where routing fractions to a common destination are identical for all sources.

This paper presents a flow routing optimization problem that can be solved using Linear Programming [LP]. Optimal Routing under changing traffic demand or capacity supply is an interesting and challenging problem [21]. Techniques have yet to be investigated to solve the problem.

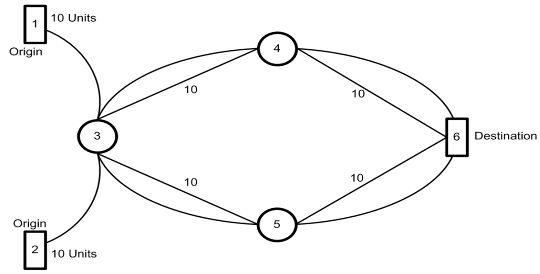

Figure 1. Flow Routing

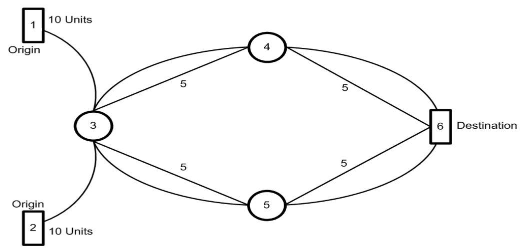

Figure 2. Destination Routing

4.2 Formulation

We define the problem as multicommodity flow problem with an objective function, which can be formulated as a Linear Program (LP). We denote each entry of traffic profile as a traffic demand between an ingress-egress pair. The linear program is described in the following equations. Refer equation (6) for the variations in the traffic demand which is described as a random parameter

We have used following notations in the formulations:

d_{ij} : Traffic demand .

I_n , O_n : Sets of Incoming and outgoing edges at vertex n respectively.

r^e_{ij} : The fraction of traffic demand for an ingress-egress pair (i, j) through edge e.

σ_k : Maximum edge utilization

t_k : Time fraction of occurrence of traffic demand.

LP formulation of the problem is described as follows:

$$\text{Minimize} \quad \sum_{k=1}^{K} t_k \, \sigma_k$$

$$\text{s. t.} \sum_{i,j} d_{ij}\, r^e_{ij} \le \sigma_k \ , \quad \forall\, e \in E, \ \ k \in (1,.., K) \tag{1}$$

$$\sum_{e \in In} r^e_{ij} = \sum_{e \in On} r^e_{ij} \ , \ \forall\, n \in \{1, --, N\} - \{i, j\} \tag{2}$$

$$\sum_{e \in Oi} r^e_{ij} - \sum_{e \in Ii} r^e_{ij} = 1, \quad \forall\, (i, j) \tag{3}$$

$$\sum_{e \in Ij} r^e_{ij} - \sum_{e \in Oj} r^e_{ij} = 1, \quad \forall\, (i, j) \tag{4}$$

$$r^e_{ij} \ \ge \ 0 \qquad \forall\, i,j,e \tag{5}$$

The first constraint along with the objective function minimizes the average maximum edge load. Second, third and fourth are flow conservation constraints. The second constraint shows that total incoming and outgoing flow is equal on any node which are not a source and destination node for the traffic demand. The third constraint ensures that total fraction going out of a source is 1 and fourth constraint is the counterpart of third at destination. The routing variable is bounded by the last constraint.

The problem of routing traffic demands to minimize congestion over multiple paths is NP- hard [19].Thus we resort to heuristic algorithms for its computation. Aim is to solve LP to get an optimal multi-path solution for each traffic demand.

After solving the LP, path decomposition will result in reduced set of paths for each traffic demand. Each path having a value assigned to it that represents the fraction of the traffic demand being routed through the path.

4.3 Solution approach and simulation set up

Routing Optimization refers to finding set of paths between pair of origin and destination routers by optimizing an objective function subjected to traffic demand and capacity constraints. Our basic approach is based on the figure 3, in which a traffic demand with network topology forms the input to a routing master program that generates a set of robust and optimal paths.

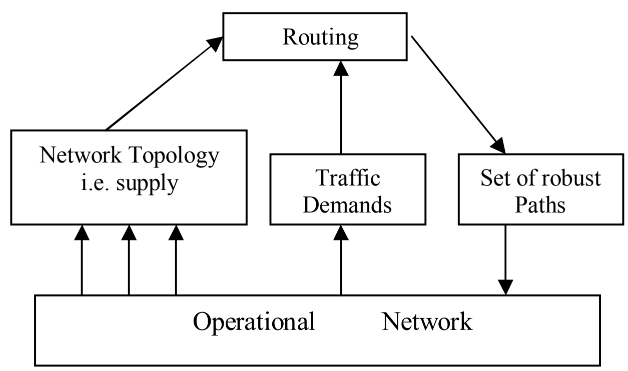

Figure 3. Diagram for our approach

The framework of routing algorithm is as follows:

INPUT: Set of nodes N, Set of edges E, traffic demand

OUTPUT: Set of robust paths

Step1: Initialize with intradomain topology.

Step2: Compute the LP of the equation 1 to 4.

Step3: Use path decomposition to compute paths. Obtain set of paths for each traffic demand. Let $x_{i,j}$ denote the fraction of traffic carried by path j of demand i. For each i, $x_{i,j}$'s sum up to 1.

Step4: Select path j according to some criteria.

For path update in step 3 and 4, we are using column generation approach. This column generation procedure will solve the subproblems for each traffic demand for the purpose of generating new columns. A master program solving each subproblem based the constraint will prove optimality of current solution. We are currently working on testing the feasibility of combining oblivious routing and dynamic routing approaches. Our goal is focus on a routing solution to trade-off between robustness and performance guarantee of the routing solution.

5. Computational experiments

We are using BRITE [20] for generating topologies. Traffic demand is modelled with Waxman where we consider three random variables for modelling traffic demand. For each node x, we chose S_x and R_x and for each pair of nodes (x, y), T(x, y) as a third variable.

If the Euclidean distance between x and y is L(x, y), then the demand between x and y can be represented as:

$$d = \alpha.\ S_{x.}\ R_{x.}\ T(x, y).\ e^{-L(x, y) / 2\Delta} \qquad (6)$$

Where the parameters in the equation (6) are defined as:

α: Waxman parameter.

$S_{x.}$ and R_x : Active senders and receivers nodes.

T(x, y): Active links.

Δ : Largest Euclidean distance between pair of nodes.

In order to accommodate the traffic variations, we are using three random variables in equation (6) to provide wide range of traffic demand.

We are using ILOG CPLEX for solving LP and optimal routing problem. Our approach is inspired by [6]. We are experimenting with random topologies as well as more realistic topologies of Rocketfuel [2] to provide robust set of solutions.

6. Conclusion and future work

We have considered the problem of routing with a range of traffic demands. The paper presented an idea on routing under the changing network conditions. The possible extension is to test the viability of algorithm under the changing traffic demands and capacity supplies.

Currently working on the hybrid approach of oblivious and online routing to combine the better of the two routing approaches.

Further plan is to deal with interdomain routing. We are currently working to understand the dynamics of interdomain demands and computation of interdomain routes. We aim to compute routing solution robust to change in interdomain traffic demand as well.

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