Traffic Engineering without Congestion Hot Spots in MPLS

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Abstract**—Traffic Engineering [1] broadly relates to optimization of the performance of the operational IP network. In networking, network congestion occurs when a link or node is carrying so much data that its quality of service deteriorates. Typical effects include queueing delay, packet loss or the blocking of new connections. A consequence of these latter two is that incremental increases in offered load lead either only to small increases in network throughput, or to an actual reduction in network throughput. This paper discusses methods like PNP approach [2] and HITS method for improving QoS [3], which are used for traffic engineering in MPLS. This paper will examine the two approaches; discuss solutions in both PNP approach and HITS method for improving QoS and point to topics for research and advanced development.**

Keywords-component; Traffic Engineering, Congestion, PNP approach, HITS, QoS

I. INTRODUCTION

The unprecedented growth of the Internet has lead to a growing challenge among the ISPs to provide a good quality of service, achieve operational efficiencies and differentiate their service offerings. ISPs are rapidly deploying more network infrastructure and resources to handle the emerging applications and growing number of users. Traffic Engineering [4] has drawn much attention in recent years. Two important components of traffic engineering are traffic estimation and routing. A good understanding of the interplay between these two inter-related components will make significant contribution to network management and performance.

Awduche et al [5] note that a distinctive function performed by Internet Traffic Engineering is the control and optimization of the routing function, to steer traffic through the network in the most effective way. Load balancing is an important approach to address network congestion problems resulting from inefficient resource allocation [6]. A routing specifies how to route the traffic between each Origin-Destination pair across a network. The objective in designing a routing is to provide good quality of service and to optimize the utilization of network resources. Measuring or estimating traffic demands accurately is non-trivial. Designing a routing robust to changing and uncertain traffic is desirable.

Common objectives of Traffic Engineering include balance traffic distribution across the network and avoiding congestion hot spots. To meet the objectives, demands have to be placed over the links in order to achieve balanced traffic distribution and to avoid congestion hot spots in the network.

A technique for monitoring network utilization and manipulating transmission or forwarding rates for data frames to keep traffic levels from overwhelming the network medium. The assumption that statistical multiplexing can be used to improve the link utilization is that the users do not reach their peak rate values simultaneously, but since the traffic demands are stochastic and cannot be predicted, congestion is unavoidable. Whenever the total input rate is greater than the output link capacity, congestion occurs. When the network becomes congested, the queue lengths may become very large in a short time, resulting in buffer overflows and cell loss. Congestion control is therefore necessary to ensure that users get the negotiated Quality of Service (QoS) [7].

We provide the background in Section II. In Section III we study the performance of both PNP approach and HITS method for improving QoS. We compare these two methods in Section IV. Then we draw to conclusions in Section V.

II. BACKGROUND

A. Graphical Models – Bayesian Networks

Graphical models are nothing but fusion of probability theory and graph theory. They provide a natural tool for dealing with two problems that occur throughout applied mathematics and engineering – uncertainty and complexity – and in particular they are playing an increasingly important role in the design and analysis of machine learning algorithms.

Probabilistic graphical models [8, 11] are graphs in which nodes represent random variables, and the arcs represent conditional independence assumptions. Hence they provide a compact representation of joint probability distributions. Undirected graphical models, also called as Markov Random Fields (MRFs) or Markov networks, have a simple definition of independence: two (set of) nodes A and B are conditionally independent given a third set, C, if all paths between the nodes in A and B are separated by a node in C. By contrast, directed graphical models also called Bayesian Networks or Belief Networks (BNs), have a more complicated notion of independence, which takes into account the directionality of the arcs.

For a directed model, we have to specify the Conditional Probability Distribution (CPD) at each node. If the variables are discrete, this can be represented as a table (CPT), which lists the probability that the child node takes on each of its different values for each combination of values of its parents.

B. Identification of Congestion Hot Spots using Bayesian approach

Currently the so-called Bayesian network approach [9] is used to identify the congestion hot spots in MPLS. With this approach, in addition to the network topology, it is necessary to specify the parameters of the nodes in the network. For each node in the network the Conditional Probability Distribution (CPD) [10] is specified. Let us illustrate this with a simple example.

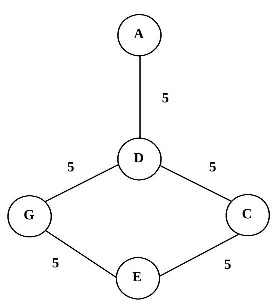


Figure 1. Bayesian Network for finding Congestion Likelihood

The network represented in Fig. 1 consists of five nodes each having link capacity of 5 units. If the nodes in the network are discrete the CPD can be represented as a table (CPT), which lists the probability that the child node takes on each of its different values for each combination of values of its parents. Here the child nodes are destination nodes and parent nodes are source nodes.

Optimal routes having minimum congestion likelihood can then be calculated using the following formula.

$$P(R = r \mid e) = \frac{P(e \mid R = r) P(R = r)}{P(e)} \tag{1}$$

where P(R = r | e) denotes the probability that random variable R has value r given evidence e. Instead of routing the demands over the congested routes, routes that suit the current traffic demand and capacity of the network are selected. The Conditional Probability Distribution for the five nodes is displayed in the following tables.

TABLE I
CPD FOR THE NODE "A"

P(A=0)	P(A=1)
0.5	0.5

TABLE II
CPD FOR THE NODE "D"

A	P(D=0)	P(D=1)
0	1	0
1	0.01	0.99

TABLE III
CPD FOR THE NODE "G"

D	P(G=0)	P(G=1)
0	1	0
1	0.9	0.1

TABLE IV
CPD FOR THE NODE "C"

D	P(C=0)	P(C=1)
0	1	0
1	0.1	0.9

TABLE V
CPD FOR THE NODE "F"

G	C	P(C=0)	P(C=1)
0	0	1.0	0.0
0	1	0.01	0.99
1	0	0.2	0.8
1	1	0.01	0.99

The new Bayesian approach is proposed for achieving traffic engineering in the backbones. Instead of relying on the mapping of logical connections of physical links to manage traffic flows in the network, we run IP routing natively over the physical topology, and control the distribution of traffic flows through setting appropriate link weights for shortest path routing.

III. TRAFFIC ENGINEERING WITHOUT CONGESTION HOTSPOTS

Multiprotocol Label Switching (MPLS) is a mechanism in high-performance telecommunications networks which directs and carries data from one network node to the next. MPLS makes it easy to create "virtual links" between distant nodes. It can encapsulate packets of various network protocols.

MPLS is a highly scalable, protocol agnostic, data-carrying mechanism. In an MPLS network, data packets are assigned labels. Packet-forwarding decisions are made solely on the contents of this label, without the need to examine the packet itself. This allows one to create end-to-end circuits across any type of transport medium, using any protocol. The primary benefit is to eliminate dependence on a particular Data Link Layer technology, such as ATM, frame relay, SONET or Ethernet, and eliminate the need for multiple Layer 2 networks to satisfy different types of traffic. MPLS belongs to the family of packet-switched networks.

A. PNP Approach

The Pragati Node Popularity (PNP) approach identifies congestion hot spots in MPLS with minimum efforts when compared to Bayesian Network approach. Pragati Node Popularity (PNP) is a numeric value that represents how popular a node is on the given network. When one node links to another node, it is effectively casting a vote for the other node. The more votes that are cast for a node, implies that the node is more popular among all other nodes in the network. PNP value is the way of finding a node's popularity. With the help of this PNP value, the congestion hot spots in the network can be identified.

Let digraph G = (V, E) represent the IP network, where V is the set of nodes and E is the set of links. Please note that the links and their capacities are directional, i.e. link i → j is considered different from link j → i, each with its own capacity. *IN(i)* and *OUT(i)* denote the number of edges "into" and "out of" node *i* respectively.

To calculate the Pragati Node Popularity (PNP) value of a node, all of its inbound links are taken into account. A PNP value of node *i*, is defined as

$$PNP(i) - (1+\delta) = \delta\gamma_i \qquad (2)$$

where δ is a constant value which can be set between 0 and 1, and γ_i is the share of the PNP value of every node that links to node *i*.

$$\gamma_i = \forall node\text{"}j\text{"}\exists edge : j \rightarrow i, \sum \frac{PNP(j)}{OUT(j)} \qquad (3)$$

In equation (3) the share means the linking node's PNP value divided by the number of out bounds links on the node. So the PNP value is determined for each node individually. Further, the PNP value of node *i* is recursively defined by the PNP of those nodes which link to node *i*.

Let *K* be the set of point to point demands. For each $k \in K$, let S_k, D_k, T_k be the source node, destination node and intermediate node respectively. Let N be the total number of nodes in the network. Then the reactive routing using PNP approach can be formulated as

$$Min \sum_i PNP(i) \qquad (4)$$

where $i \in T_k$, $i \notin S_k, D_k$

Subject to

$$\forall i \in V, PNP(i) > 0 \qquad (5)$$

$$\forall i \in V, \sum_i PNP(i) = N \qquad (6)$$

The objective function (4) is to minimize congestion by selecting a route with nodes having least PNP values as intermediate nodes. Constraints (5) and (6) are node popularity conservation constraints. Equation (5) says that, nodes having zero PNP value must not be considered for routing process. Because they indicate that the path has been broken down. Equation (6) says that the net popularity value of a network is equal to the total number of nodes in the network.

B. HITS method to improve QoS

Given a network topology and existing traffic flows, the Hits algorithm can be used to identify the congested nodes in the network. The nodes in the IP network can be considered as the pages of HITS algorithm.

Jon Kleinberg's algorithm called HITS (Hyperlink Induced Topic Search) [15] identifies good authorities and hubs for a topic by assigning two numbers to a page *i*: an authority weight a_i, and a hub weight h_i. These weights are defined recursively. Pages with a higher a_i number are considered as being better authorities, and pages with a higher h_i number as being better hubs.

$$a_v = \sum_{u \rightarrow v \in E} h_u \qquad (7)$$

$$h_u = \sum_{u \rightarrow v \in E} a_v \qquad (8)$$

Let *A* be the adjacency matrix of the graph *G*, A^t be the transpose of the matrix and *v* be the authority weight vector and *u* be the hub weight vector. Then,

$$v = A^t.u \qquad (9)$$

$$u = A.v \qquad (10)$$

where,

$$u = \begin{bmatrix} h_1 \\ h_2 \\ \dots \\ h_n \end{bmatrix} \quad \text{and} \quad v = \begin{bmatrix} a_1 \\ a_2 \\ \dots \\ a_n \end{bmatrix}$$

The initial hub and authority weights of the nodes are,

$$u_0 = \begin{bmatrix} 1 \\ 1 \\ .. \\ 1 \end{bmatrix} \quad (11)$$

$$v_0 = A^t . \begin{bmatrix} 1 \\ 1 \\ .. \\ 1 \end{bmatrix} \quad (12)$$

After k steps, the authority and hub weights are calculated using

$$v_k = (A^t . A).v_{k-1} \quad (13)$$

$$u_k = (A.A^t).u_{k-1} \quad (14)$$

Let digraph G = (V, E) represent the IP network, where V is the set of nodes and E is the set of links. Please note that the links and their capacities are directional, i.e. link i → j is considered different from link j → i, each with its own capacity. Let A represents the Adjacency matrix of the IP network. The hub and authority weights (h and a respectively) are represented by single column matrixes. For any given traffic flow S be the source of the flow, D be the destination of the flow and intermediate nodes are denoted by Ij. Then the congestion hot spots identification using HITS algorithm is formulated as follows.

$$\text{Min } \forall I_j \in I : \sum_j a_{Ij} + h_{Ij} \quad (15)$$

Subject to

$$a_{Ij} >= 0 \quad (16)$$

$$h_{Ij} >= 0 \quad (17)$$

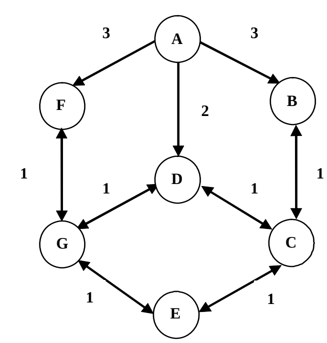
$$0 \le j \le n \quad (18)$$

The objective function is to minimize congestion by selecting a route with nodes having least hub and authority weights. Here in equation (15) only intermediate nodes are taken into consideration. Equations (16) and (17) say that the authority and hub weights may be either zero or some positive value. It never takes negative values. Equation (18) says that the number of intermediate nodes in a path may be zero or less than the number of intermediate nodes in the path. The above LP formulation is not restricted for the given example network but they can be generalized to any network topology.

IV. COMPARISON BETWEEN PNP AND HITS

Let us consider the network shown in Fig. 2. It shows a simple network topology, link weights, and traffic demands. Each link has a capacity of 5 units and each demand needs bandwidth of 4 units. The link capacities, link weight and traffic demands are directional in IP networks.

Since the network here is rather small, the process of traffic engineering can be done manually. The optimal routes for achieving balanced traffic distribution are as follows. By using equal-cost load balancing in the OSPF routing protocol [12],



A->B: 4 A-B
A->F: 4 A-F
B->F: 2 B-C-D-G-F
B->F: 2 B-C-E-G-F
A->E: 2 A-D-G-E
A->E: 2 A-D-C-E
F->B: 2 F-G-D-C-B
F->B: 2 F-G-E-C-B

Figure 2. Topology, Link Weights and Traffic Flows

Demand A to B uses path AB, and demand A to F uses AF. Demand B to F has two paths. Half of the demand goes over BCEGF and the other half over BCEGF. BCDGH and BCFGH appear as equal-cost paths, so routing protocols such as OSPF will perform load sharing over them. Similarly for A to E. Half of the demand traverses path ADCE and the other half traverses through ADGE. Optimal routes and traffic distribution are given in Fig. 2.

A. *Calculation of PNP values*

Because of the size of the nodes in the Internet backbones, the Pragati Node Popularity (PNP) approach uses an approximate, iterative computation of PNP values. This means that each node is assigned an initial starting value and the PNP values of all nodes are then calculated in several computation circles based on the equations (2) and (3) determined by the PNP approach. The iterative calculation is illustrated using the example network in Fig.2, whereby each page is assigned a starting PNP value of 1 and constant value as 0.85 to strike better results. The PNP values for Fig. 2 are listed in Table. I.

TABLE I
PNP VALUES FOR THE NETWORK IN FIGURE 2

Itera-tion	Pragati Node Popularity values						
	A	**B**	**C**	**D**	**E**	**F**	**G**
0	1.000	1.000	1.000	1.000	1.000	1.000	1.000
1	0.150	0.717	1.850	1.000	0.717	0.717	1.850
2	0.150	0.717	1.489	1.241	1.198	0.717	1.489
3	0.150	0.614	1.796	1.036	0.994	0.614	1.796
4	0.150	0.701	1.535	1.210	1.168	0.701	1.535
5	0.150	0.627	1.757	1.062	1.020	0.627	1.757
6	0.150	0.690	1.568	1.188	1.145	0.690	1.568
7	0.150	0.637	1.728	1.081	1.039	0.637	1.728
8	0.150	0.682	1.592	1.172	1.129	0.682	1.592
9	0.150	0.644	1.708	1.095	1.052	0.644	1.708
10	0.150	0.676	1.610	1.160	1.118	0.676	1.610
11	0.150	0.649	1.693	1.105	1.062	0.649	1.693
12	0.150	0.672	1.622	1.152	1.109	0.672	1.622
13	0.150	0.652	1.683	1.112	1.069	0.652	1.683
14	0.150	0.669	1.631	1.146	1.103	0.669	1.631
15	0.150	0.655	1.675	1.117	1.074	0.655	1.675
16	0.150	0.667	1.638	1.142	1.099	0.667	1.638
17	0.150	0.657	1.669	1.121	1.078	0.657	1.669
18	0.150	0.665	1.642	1.138	1.096	0.665	1.642
19	0.150	0.658	1.665	1.123	1.081	0.658	1.665
20	0.150	0.664	1.646	1.136	1.094	0.664	1.646

It is seen that good approximation of the real PNP values can be calculated using few iterations alone. It is clear that the nodes C and G are the most congested node in the network. Because three different traffic flows, A→E, B→F and F→B are using these two nodes. Next to them node D is the most congested one. Likewise it can easily predict the congested nodes in any given network.

B. *Calculation of Hub and Authority values using HITS*

The nodes in the IP network can be considered as the pages of HITS algorithm. The Source nodes S are considered as Hubs and the Destination nodes D are considered as Authorities. The Intermediate nodes I between any source and destination may act either as a hub or as an authority. Let us first illustrate with a simple example how the HITS algorithm can be implemented in a network. Let us consider the network shown in Fig. 2. The vertices and the edges are represented below. Here edges here

$$G = (V, E)$$
$$V = (A, B, C, D, E, G, F)$$
$$E = (\langle AB \rangle, \langle AF \rangle, \langle AD \rangle, \langle BC \rangle, \langle CD \rangle, \langle CE \rangle, \langle DC \rangle, \langle DG \rangle, \langle EG \rangle, \langle GE \rangle, \langle GF \rangle)$$

Here S={A, B,F}, D={B,E,F} and I={B,C,D,E,G}

$$A = \begin{bmatrix} 0\,1 & 0\,1 & 0\,0\,1 \\ 0\,0\,1 & 0\,0\,0\,0 \\ 0\,0\,0\,1 & 1 & 0\,0 \\ 1 & 0\,1 & 0\,0\,1\,1 \\ 0\,0\,0\,0\,0\,1 & 0 \\ 0\,0\,0\,0\,1 & 0\,1 \\ 0\,0\,0\,0\,0\,0\,0 \end{bmatrix}$$

Using (11), (12), (13) and (14), we get,

$$a_0 = \begin{bmatrix} 8 \\ 6 \\ 10 \\ 10 \\ 9 \\ 10 \\ 19 \end{bmatrix} \qquad h_0 = \begin{bmatrix} 35 \\ 10 \\ 19 \\ 47 \\ 10 \\ 28 \\ 0 \end{bmatrix}$$

Then I_j is calculated using equation (15).

$$I = \begin{bmatrix} 70 \\ 50 \\ 56 \\ 111 \\ 56 \\ 50 \\ 70 \end{bmatrix}$$

According to HITS the congestion index is high for the node D. From the calculations it is clear that when we take D as intermediate node the congestion will be very high. Next to that there comes A and G. Likewise we can predict whether the path is congested or not using HITS.

C. *Comparison between PNP and HITS congestion index*

For example, let us consider in Fig. 2, there comes a new flow from E→A. Multiple paths are available from E→A. They are E→C→D→A, E→C→B→A, E→G→D→A and E→G→F→A etc.

While applying the PNP approach, the objective function (4) will select the route E→C→B→A. Because, it is the one having least net PNP value when compared with the remaining routes. All other routes are having higher net PNP values. So the path E→C→B→A, can be chosen for data transmission between node E and A. It is illustrated in Table II.

TABLE II
PATH SELECTION USING PNP APPROACH

Feasible Paths	Summation of hub and authority values of Intermediate nodes
E-C-B-A	1.646+0.664=2.310
E-C-D-A	1.646+1.136=2.782
E-G-D-A	1.646+1.136=2.782
E-G-F-A	1.646+0.664=2.310

If we calculate the congestion index using HITS method of improving Quality of Service, the objective function (15) will select the route E→C→B→A. Because, it is the one having least hub and authority weight when compared with the remaining routes. So the path E→C→B→A, will be selected for data transmission between node E and A.

TABLE III
HUB AND AUTHORITY CALCULATION

Feasible Paths	Summation of hub and authority values of Intermediate nodes
E-C-B-A	56+50=106
E-C-D-A	56+111=167
E-G-D-A	70+111=181
E-G-F-A	70+50=120

From the above calculation it is clearly shown that both the methods will yield same result. For making comparison with PNP values, the HITS congestion index is converted to numbers with two decimal places.

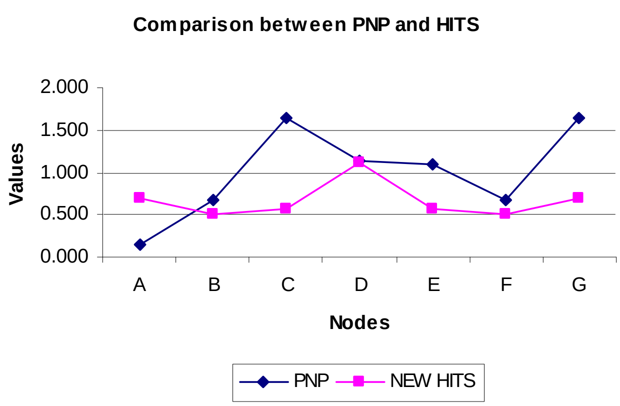


Figure 3. Comparison chart

V. CONCLUSION

We observe that both the PNP approach and HITS method of improving QoS, will effectively identify the congestion hot spots in operational IP networks. Both the methods can identify the congestion hot spots with no knowledge of link weights and shortest paths but with the help of the network topology alone.

Furthermore, it overcomes the draw back on "N-square" problem of Bayesian approach. Similar approaches have been tried by some service providers in the past. When a link is experiencing congestion, service providers typically increase the weight for that link in the hope that traffic will be moved away from it. These experiments, however, were done based on simple heuristics. The lack of systematic strategy and comprehensive studies of link weight change impact has prevented it from being widely adopted in operational backbone networks.

Whenever there is new traffic demand and path selection procedure by either PNP approach or HITS method of improving quality of service, the IN and OUT values of the nodes and the adjacency matrix must be updated accordingly. The updation is made in order to reflect the changes in traffic flows in the network. The complexity of the HITS method is greater when compared to that of PNP approach. Irrespective of the network topology these methods identify the congestion hot spots efficiently and achieve the common goal of Traffic Engineering [1].

With the help of PNP approach or HITS method of improving QoS, we not only find the congested nodes in the network, but also find a better route than the congested ones. Even though the path suggested by either PNP approach or HITS method may be longer than the shortest path, but it reduces the queuing due to congested routes. Thus, with these methods we improve the quality of routing to almost perfection there by avoiding congestion hot spots in the network.

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