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Bi-Criteria Latency Optimization of Intra-and Inter-Autonomous System Traffic Engineering

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***Abstract*—**Traffic Engineering (TE) is the process of controlling how traffic flows through a network in order to facilitate efficient and reliable network operations while simultaneously optimizing network resource utilization and traffic performance. TE improves the management of data traffic within a network and provides the better utilization of network resources. Many research works considers intra and inter Traffic Engineering separately. But in reality one influences the other. Hence the effective network performances of both inter and intra Autonomous Systems (AS) are not optimized properly. To achieve a better Joint Optimization of both Intra and Inter AS TE, we propose a joint Optimization technique by considering intra-AS features during inter – AS TE and vice versa. This work considers the important criterion say latency within an AS and between ASes. and proposes a Bi-Criteria Latency optimization model. Hence an overall network performance can be improved by considering this joint-optimization technique in terms of Latency.

***Keywords*—**Inter-Domain Routing , Measurement, Optimization Performance, Traffic Engineering.

I. INTRODUCTION

TRAFFIC Engineering is one of the promising tools that provide QOS across the Internet. The need for Traffic Engineering includes Quality of Service (less latency, Higher through put, less packet loss, Higher Bandwidth), Interdependent tunable parameters, network growth, traffic variability and multicasting. These drive the need for better TE tools. Hence works on traffic Engineering focuses predominantly on Interior Gateway Protocols (IGPs) such as OSPF, IS-IS, and MPLS, which control the flow of traffic within an Autonomous system. But most traffic in a large backbone network traverses multiple domains, making interdomain traffic an important part of traffic Engineering..

Traffic engineering is performed by means of a set of techniques that can be used to better control the flow of packets inside an IP network. Here a small number of sources are responsible for a large fraction of the traffic. Across inter-domain boundaries, traffic engineering relies on a careful tuning of the route advertisements sent via the Border Gateway Protocol (BGP). This tuning can be used to control the flow of the incoming and of the outgoing traffic and identify their limitations. Several Internet Service Providers (ISPs) rely on traffic engineering to better control the flow of IP packets. Large ISPs often need to engineer the flow of packets inside their own domain to reduce congestion by better distributing the traffic on all their links. To remedy this situation, the techniques that tune the traditional IP routing protocols used inside the ISP network, is required. Besides optimizing the flow of packets inside their network, most ISPs also need to better control the flow of their inter-domain traffic, i.e. the IP packets that cross the boundaries between distinct ISPs. Internet Service Providers typically carry both intra –AS traffic that is routed only within their networks and inter-AS traffic that is routed not only within their networks but also across other ASes. The Border Gateway Protocol is the current de facto standard inter-domain routing protocol. Hence the only solution to engineer the flow of inter-domain traffic is to tune the configuration of the BGP routing protocol. However this tuning has its own limitations.

Our Internet, which is an interconnection of multiple networks called domains or Autonomous Systems is composed of more than 25,000 ASes that collectively advertise more than 200,000 IPv4 prefixes, and these statistical numbers are still increasing. This interdomain routing system is one of the largest distributed systems today. Each domain should be able to select and distribute to its peers, the best path to reach each destination. The autonomous systems interact and coordinate the IP traffic delivery, exchanging routing information using this BGP protocol. This BGP is a complex protocol which enforces various economical relationships among domains.

Previous research works on intra-AS traffic Engineering has assumed that ingress and egress points of inter-AS traffic do not change. Also prior inter-AS traffic does not consider the optimization of routes inside an AS. A true overall Traffic Engineering solution cannot be obtained when each Traffic Engineering is considered separately.

II. INTRA- AND INTER- AUTONOMOUS SYSTEM TRAFFIC ENGINEERING:

In general Traffic Engineering requires understanding of the network paths and traffic volume associated with each destination prefix and the Collection of BGP routing tables and flow level traffic measurements from the routers that connect the AS with other large providers. Also it requires elements such as traffic matrix, topology of the network and the routing algorithms. Inter-domain traffic Engineering can be evaluated by reproducing the state of BGP routing inside a large network. In inter-domain traffic engineering, a primary concern is the size of the inter-domain topology for the majority of the traffic.

Internet traffic received by an Autonomous system is categorized into four types. *Internal traffic* that travels from an ingress access link to an egress access links, *Inbound traffic* that travels from an ingress peering link to an egress access link, *Outbound traffic* that travels from an ingress access link to an egress peering link and the *transit traffic* from an ingress peering link to an egress peering link.

In the internet, most traffic traverses across multiple domains. Hence it is necessary to engineer the traffic between ASes. For example, congestion normally occurs in the links that connects two domains. So a part of the traffic can be diverted through less congested links. Sometimes the Bandwidth will be increased in the links that connect two domains. Also communication between two Ases is established on commercial basis. The two domains that participate can have an agreement that restricts the amount of traffic they exchange. If there is any violation in that agreement, one of the AS has to redirect the traffic through other neighboring domain.

Traffic Engineering takes input elements such as traffic matrix, topology of the network and algorithms for producing a set of traffic routing plans that optimize the overall network performance. Following are the types of internet traffic:

- *Local intra-AS traffic*: Inbound traffic within an AS which is destined to egress Access links.
- *Inter-AS traffic*: Traffic that is destined at downstream ASes whose egress peering points can be varied by inter-AS traffic Engineering. This is what is called transit traffic.
- *Intra AS traffic*: all traffic that traverses the network including both local intra-As and inter-AS traffic.

For ease of presentation table 1 shows the notations used throughout this paper.

A traffic matrix is a matrix of traffic load from one network point to another one over a particular time interval.

As given in table 1, $t\_inter(i, k)$ is an element of inter –AS traffic matrix, which represents the volume of inter-AS that enters the network at ingress point I and is destined to routing prefix k. In the intra-AS traffic matrix, each element $t\_intra(i, j)$ represents the volume of traffic that enters the network at ingress point i and exits at egress point j. It is the sum of the local intra-AS and inter-AS traffic volume between each ingress and egress node pair.

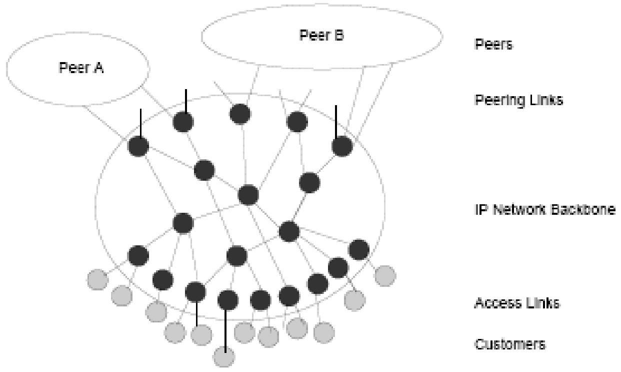

Fig. 1. IP network components and terminologies.

TABLE I
NOTATIONS USED IN THIS PAPER

Notation	Description
K	A set of Down Stream routing Prefixes.
I	A set of Ingress points
J	A set of Egress points(Inter AS links)
E_{intra}	A set of inter AS links
$t\text{-}inter(i,k)$	Bandwidth demand of the inter- AS traffic flow at ingress point $i \in I$ destined to routing prefix $k \in K$
$t\_loc(i, j)$	Bandwidth demand of local intra-AS traffic flow between ingress point $i \in I$ and egress point $j \in J$
$t\_intra(i, j)$	Bandwidth demand of the intra- AS traffic flow between ingress point $i \in I$ and egress point $j \in J$
$d\text{-}inter(i,k)$	Delay of the inter- AS traffic flow at ingress point $i \in I$ destined to routing prefix $k \in K$
$d\_intra(i, j)$	Delay of the intra- AS traffic flow between ingress point $i \in I$ and egress point $j \in J$
$T\text{-}Inter(I, K)$	Inter AS (ingress to prefix) traffic Matrix consisting of all $t\text{-}inter(i,k)$
$T\_loc(I, J)$	Local intra-AS (ingress to egress) consisting of all $t\_loc(i , j)$
$T\_Intra(I, J)$	Intra – AS traffic matrix consists of all $t\_intra(i, j)$
$x^{j}_{i,,k}$	A binary variable indicating whether inter-AS traffic flow $t\_inter(i, k)$ is assigned to egress point j.
$y^{l}_{i,k}$	A binary variable indicating whether intra-AS traffic flow $t\_inter(i, j)$ is assigned to intra-AS link l.
$P_{i,j}$	A set of candidate path realizing intra-AS traffic flow $t\_intra(i, j)$

$W_{i,j,p}$	A binary variable indicating whether path $p \in P_{i,j}$ is chosen to realize the traffic flow *t_intra(i, j)*

III. NEED FOR LATENCY OPTIMIZATION IN INTRA- AND INTER-DOMAIN TRAFFIC ENGINEERING:

In a network, latency, a synonym for *delay*, is an expression of how much time it takes for a packet of data to get from one designated point to another. In some usages latency is measured by sending a packet that is returned to the sender and the round-trip time is considered the latency. The latency assumption seems to be that data should be transmitted instantly between one point and another (that is, with no delay at all). The contributors to network latency include:

- Propagation: This is simply the time it takes for a packet to travel between one place and another at the speed of light.
- Transmission: The medium itself (whether optical fiber, wireless, or some other) introduces some delay. The size of the packet introduces delay in a round trip since a larger packet will take longer to receive and return than a short one.
- Router and other processing: Each gateway node takes time to examine and possibly change the header in a packet (for example, changing the hop count in the time-to-live field).
- Other computer and storage delays: Within networks at each end of the journey, a packet may be subject to storage and hard disk access delays at intermediate devices such as switches and bridges. (In backbone statistics, however, this kind of latency is probably not considered.)

Network proximity and latency estimation is an important component in discovering and locating services and applications. With the growing number of services and service providers in the large-scale Internet, accurately estimating network proximity/latency with minimal probing overhead becomes essential for scalable deployment. One of the most important issues impacting global firms is how to increase speed and reduce latency when accessing data. Internet Users need to be confident that things are to be executed with the least possible latency. A Bi-Criterion latency Optimization model that analyzes and optimizes the network for low-latency performance is what is needed. Only then the network can deliver the service levels required by high-performance applications. All the optimization techniques try to find out the optimal solution for the problems. But because of the huge amount of complex parameters in real time systems, it is difficult to obtain the optimal solution in many cases using traditional approach. In that case, it is a common practice to choose the satisfactory solution than the optimal solution. Also in traditional techniques, the optimal solutions are obtained by optimizing a single parameter, by having the other parameters constant. A Bi-criterion optimization problem gives an optimal solution in which each of the two objectives of the problem simultaneously attains an optimal value. In some scenarios, the two objectives may be conflicting. One such example is Traffic Engineering between Autonomous systems that involve both intra- and inter-domain links. Here the latency of a particular egress point may be low but the latency of the intra-AS path towards that egress point may be high. Also the latency function depends on the maximum segment size of the packet, Bandwidth of the links involved, type of TCP flow, etc. Hence comparing two objectives values, when the number of intra- and inter- AS links and their capacities are different, will not be perfect. This paper introduces a latency optimization problem that leads to a non-dominated satisfactory solution while trying to optimize intra- and inter AS TE.

IV. BI-CRITEIA LATENCY OPTIMIZATION MODEL

A Bi-Criteria Optimization formulation is one, by which two concepts that are of concern can be expressed to represent an optimal solution. Their objectives are typically expressed in the form of latency functions. This paper formulates Bi-Criteria Joint TE problem by taking into account both intra- and inter- AS TE latency functions.

A. Mathis et al equation for Round Trip Time:

Ultimately Traffic Engineering is performed to achieve Congestion avoidance. This paper proposes a Bi-Criterion Latency Optimization model for intra- and inter- autonomous system Traffic Engineering which is based on Mathis et al equation. Here the latency function is taken to be a piecewise linear function of Round Trip Time which imitates the response time of M/M/1 queues to represent the latency of network links. By using the piecewise linear latency function, two objectives of minimizing the delay and packet drop probability are taken into account simultaneously. This paper uses the piecewise linear latency function for both intra- and inter- AS TE for consistency and generality. Nevertheless these latency functions may be different by domains according to their operational objectives. Recent Studies by Mathis et al shows the Steady State of the throughput model of the saw-tooth behavior of TCP Congestion Avoidance algorithm. Mathis et al derived the following formula of a single TCP flow:

$$BW = \frac{MSS}{RTT}\frac{C}{\sqrt{p}} \tag{1}$$

where *MSS* is the maximum segment size, *C* is a constant which is dependant on the type of TCP, and *p* is the packet drop probability. Hence from equation (1), we can obtain an equation for round trip time for the same flow:

$$\mathbf{RTT} = \frac{MSS}{BW} * \frac{C}{\sqrt{p}} \tag{2}$$

B. Bi-Criteria Problem Formulation:

The objective of the joint TE problem is to minimize both intra- and inter- AS delays:

$$Minimize \sum_{inter} \alpha + \sum_{intra} \beta \tag{3}$$

Subject to

$$\alpha = f_e(RTT_e) \tag{4}$$

$$\beta = f_a(RTT_a) \tag{5}$$

$$RTT_e^j = \sum_{i\varepsilon I} \sum_{k\varepsilon K} \frac{MSS}{t\_inter(i,k)} * \frac{C}{\sqrt{p}} * x_{i,k}^j \tag{6}$$

$$RTT_a^l = \sum_{i\varepsilon I} \sum_{j\varepsilon J} \frac{MSS}{t\_intra(i,j)} * \frac{C}{\sqrt{p}} * y_{i,j}^l \tag{7}$$

$$\sum_{p\varepsilon P_{i,j}} w_{i,j,p} = 1, \forall \; (i \,\varepsilon\, I, j \,\varepsilon\, J) \tag{8}$$

Equations (6) and (7) define the round Trip Time of intra- and inter- AS links. Equation (8) ensures that *t_intra (i, j)* is routed along a single LSP within a network. This constraint maintains scalability and minimizes complexity on network management by avoiding excessive LSPs to be managed and traffic splitting. Equations (4) and (5) define the latency of each intra- and inter- AS link as a function of its Round Trip Time based on piecewise linear latency function. Fundamentally, the Joint-TE problem is the combination of intra- and inter-AS TE problems. The problem formulation of intra-AS TE consists of the reduced objective function $Minimize \sum_{intra} \beta$ as well as constraints (5), (7) and (8). On the other hand, the problem formulation of inter-AS TE consists of the reduced objective function $Minimize \sum_{inter} \alpha$ as well as constraints (4) and (6).

V. TRAFFIC ENGINEERING ALGORITHM SELECTION

Joint Traffic Engineering problem can be solved using intra- and inter- AS TE algorithms. These algorithms results in near optimal solutions. A Heuristic algorithm proposed by Sridharan et al [8] is used as the intra- AS TE algorithm. The algorithm solves the intra- AS TE problem with the piecewise linear delay function. The algorithm is mainly used to solve the intra- AS TE problem formulation that results in optimal routing solution. This optimal heuristic algorithm is followed by a greedy heuristic that tries to avoid the traffic distribution through multiple streams for an ingress-egress router pair. The same optimal heuristic algorithm is used for inter-AS TE problems, since prior [9] inter -AS TE problems used it, which resulted in near-optimal solution. The algorithm goes like the following steps:

1. The LP formulation of intra- and inter-AS TE is solved using AMPL and CPLEX optimization engine. This results in inter-AS link delays.
2. Set the desired inter-AS link utilization as capacity constraints. This constraint ensures that the total traffic on each inter-AS link does not exceed the desired utilization.
3. Sort the inter-AS traffic flows in descending order according to the traffic demand. Assign each traffic flow in that order to the egress point from which the inter-AS link starts and whose delay value is the lowest.
4. If there exists unassigned traffic flows, remove the capacity constraints and re-run the previous steps until all the flows are assigned with links.

VI. METHODOLOGY FOR JOINT TE

Here a methodology for optimization is discussed. Howarth et al [1] presented a strategy called integrated optimization for their inter-AS cost optimization which produces near optimal solution. The same methodology is adopted here to solve the inter-AS latency optimization problem.

A. Integrated Optimization:

This method simultaneously solves the intra- and inter-AS TE objectives. This approach needs starting solutions as inter-AS and intra-AS routing configurations with known egress points and ingress to egress paths. These starting solutions can be either optimized or not. This integrated optimization technique enhances the quality of the starting solution by applying Neighborhood Search Algorithm [NSA]. The solutions produced by this method are much better than the input solution.

B. NSA Description:

Let x be the starting solution. N(x) be the solution space of x identified as the neighborhood by NSA. By making a single move on x, the neighbors of x can be obtained. In this current new solution space, a best solution is taken, which is treated as the current solution. This searching procedure continues until the stopping criterion is reached. And the current solution at the end of the iteration is the best optimal solution. A memory list is used to avoid looping. A solution is rejected, if it is there already in the memory list. The other components of the algorithm are described below:

C. Starting Solution:

Starting solution for inter-AS is obtained by choosing an egress point in random. And the intra-AS routing is executed by the shortest hop path at the starting state. They are considered as non-optimal solutions.

D. Neighborhood Solution Space Structure and Searching Techniques:

The neighborhood solution space structure is based on moving the traffic flow from egress point to the other best egress point and also by re-routing the traffic flow of ingress to that egress router. It is based on the following transformation procedure: The path delay is defined as the sum of the delay of the inter-AS link and the delay of each link on the intra-AS route to which an inter-AS traffic flow has been assigned. Here an intermediary factor, say α, is introduced to identify all the combinations of intra- and inter-AS delays.

For each inter-AS traffic flow,
Calculate

Saved delay period = delay reduced minus *delay increased*

where

Delay reduced = path delay of the traffic flow minus *path delay of the traffic flow that would have been removed.*

For each potential egress point, except the currently assigned to the inter-AS traffic flow, Calculate,

Delay increase = delay of the new path towards the potential egress point that the traffic flow would have been assigned minus *delay of the original path towards this egress point.*

where new path is the minimum delay path that can be found by Dijkstra's algorithm using the instantaneous intra-AS link delay as the routing metric.

Delay reduced reflects how much delay would have been reduced if the traffic was removed on the path.

Delay increased reflects how much delay would have been increased when the traffic flow is assigned onto a new egress point.

For each iteration our neighborhood search strategy chooses the first solution with positive *Saved delay period*.

E. Memory List and Stopping Criterion:

The memory list used to store the visited solution is FIFO queue. The size of the list depends on the nature of the problem. Stopping Criterion also depends on the nature of the problem. Here the maximum number of iterations are taken to be the stopping Criterion. This number is not chosen arbitrarily instead it is related to the number of inter-AS traffic flows.

F. Neighborhood Search Algorithm:

```
count ← 0
while count < Max_count
    count ← count + 1
    If ( no progress in delay for a certain no. of iterations) then { perform intra-AS TE on the current solution }
    For each inter-AS traffic flow t_inter(i, k)
        f(i, k) ← s(i, k) /* Starting egress point assigned to current solution*/
        $\Phi \leftarrow \alpha \psi_{s(i,k)} (RTT_e^{s(i,k)} + \sum_{l \in p \in P_{i,j} : w_{i,j,p}=1} \gamma_l (RTT^l_a)$
        /* Delay of the path that excludes the inter-AS traffic*/
        $\Phi' \leftarrow \alpha \psi_{s(i,k)} (RTT_e^{s(i,k)} + d\_inter(i,k)) + \sum_{l \in p \in P_{i,j} : w_{i,j,p}=1} \gamma_l (RTT^l_a + d\_inter(i,k))$
        /* delay of the path through which the inter-AS traffic flows. */
        delay reduced ($\Delta$) ← $\Phi' - \Phi$
        For each potential egress point, i.e., j Є out(k), which does not constitute a move in the memory list,
            delay increase = $\Delta' = \Omega - \Omega'$ where
            $\Omega \leftarrow \alpha \psi_j (RTT_e^j) + \sum_{l \in p \in P_{i,j} : w_{i,j,p}=1} \gamma_l (RTT^l_a)$
            $\Omega' \leftarrow \alpha \psi_j (RTT_e^j + d\_inter(i,k)) + \sum_{l \in p \in P_{i,j} : w_{i,j,p}=1} \gamma_l (RTT^l_a + d\_inter(i,k))$
            where $\Omega$ is obtained by assigning the traffic flow towards the potential egress point by virtually releasing the resources used by t_inter(i, k) on $p \in P_{i,j} : w_{i,j,p} = 1$
            Recompute intra-AS path z between ingress point I and egress point j
            If $\Delta \geq \Delta'$ then /* delay reduced ≥ delay increase */
                $\Delta \leftarrow \Omega - \Omega'$
                f(i, k) ← j
                sel_path ← z
        If f(i, k) ≠ s(i, k)
            Break the most outer loop
If f(i, k) ≠ s(i, k)
    Update resource utilization on intra- and inter- AS link wth respect to the new assignment
    Replace $p \in P_{i,j} : w_{i,j,p} = 1$ by sel_path
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25. Add t_inter(i, k ) to t_intra(i, f(i,k)
26. s(i, k) ← f(i, k)
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VII. EVALUATION METHODOLOGY:

This section proposes the evaluation methodology to analyze the performances of various strategies proposed previously for the joint TE problem.

A. Traffic Demands for implementation:

Traffic matrices can be computed withdifferent levels of aggregation with source and destination end-points, for example at the level of PoP to PoP, router to router, link to link. This paper uses the PoP to PoP traffic matrix which may be useful for a number of Traffic Engineering applications.

Traffic Matrices are generated for evaluations of the performances of inter -AS TE and intra-AS TE. Traffic demands can be obtained by adopting a measurement methodology that combines the flow level measurements collected at all ingress links with reachability information about all egress links[10]. The traffic demand ultimately consists of an ingress link, a set of egress links and a volume of load. Normally a given destination is typically reachable from multiple edge routers. IP traffic demands are naturally modeled as point-to-multipoint volumes. Here the multipoints are nothing but the set of egress links that depend on the ISP's routing policies and the BGP advertisements received from neighboring domains. The selection of a unique link from this set depends on intra-domain routing information. Selection of an ingress link need not be taken into consideration and can be chosen random, for which the set of egress links are addressed.

Traffic matrix [11] gives the amount of traffic transmitted between all possible pairs of origin node and destination node in a network during a certain period of time. The traffic matrix supports in various tasks such as network control and management tasks, including service provision, load balancing, routing protocol design, network reliability analysis, and network anomaly detection. One method to derive the traffic matrix for an IP network is to use tools like NetFlow [10]. NetFlow can be implemented at the ingress routers, which helps to aggregate packets that match in the key IP and TCP/UDP header field (e.g., source and destination addresses, TCP port number) into flows. However, this method consumes a significant amount of CPU resource of routers because it requires the routers to keep per flow information. In addition, constructing the traffic matrix at the router level or points-of-presence (PoP) level from NetFlow data is not a easy task since one needs to associate flow information with routers or PoPs, using data collected from router configuration files and forwarding tables.

An alternative approach is to estimate the traffic matrix based on link traffic measurements. In IP networks, link traffic measurements (link counts) can be readily collected via the *Simple Network Management Protocol* (SNMP). This generation and estimation of traffic matrix is purely based on the references [11] [12] [15]. According to those references, we use the equation,

$$Y=Ax \tag{9}$$

where $x= (x_1, \ldots, x_n)^T$, where x_i is the amount of traffic transmitted per unit time between the i-th OD pair and $y = (y_1, \ldots, y_m)^T$ be the vector of link counts, where y_j denotes the aggregate traffic of all OD pairs transmitted (per unit time) on link j. Here n denotes the number of OD pairs and m denotes the number of links in the network. Let $A = (A_{ji} : 1 \le j \le m, 1 \le i \le n)$ denote the routing matrix, where A_{ji} is the proportion of the traffic of the i-th OD pair transmitted on link j. $A_{ji} = 0$ if the traffic of the i-th OD pair does not traverse link j. If the route of every OD pair is fixed and unique, then A is a 0-1 matrix. The routing matrix can be obtained by gathering the network topology and link weights information, and then computing the shortest-paths of all OD pairs [12]. Equation (9) is a generalized vector equation and the individual elements of the vector matrix can be obtained by

$$y_j = \sum_i A_{ji} x_i, \text{ for all } j \tag{10}$$

At this point the main objective is to estimate the traffic matrix x based on collected link counts y. In a real network, there are typically many more OD pairs than links [12], [13] and [14], i.e., $n >> m$. Hence there exist infinitely many solutions to equation (9).

A small scale network with 4 nodes topology is considered for traffic matrix estimation as depicted in Figure 2 and solved using gravity model approach[15]

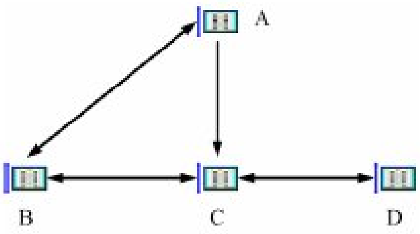

Fig. 2. 4-NodeTopology

In this topology, each node represents a Point-of-Presence (POP) and each link represents the aggregated connectivity between the routers belonging to a pair of adjacent POPs (i.e., inter-POP links). Tang et al [15] analyzed four various methodologies to obtain the best traffic matrix for the above topology and identified a best traffic matrix using an algorithm called Expectation Error Rectify Algorithm (EERA). Hence the traffic matrix is directly taken from [15] for this research work. The Traffic Matrix is given below:

TABLE II
TRAFFIC MATRIX

OD pairs	Traffic Volumes
AB	318
AC	297
AD	304

BA	300
BC	271
BD	288
CA	293
CB	290
CD	311
DA	289
DB	282
DC	280

VIII. RESULTS AND DISCUSSIONS:

We have evaluated the overall inter-AS delays and intra-AS delays for nearly 30 set of traffic demands.

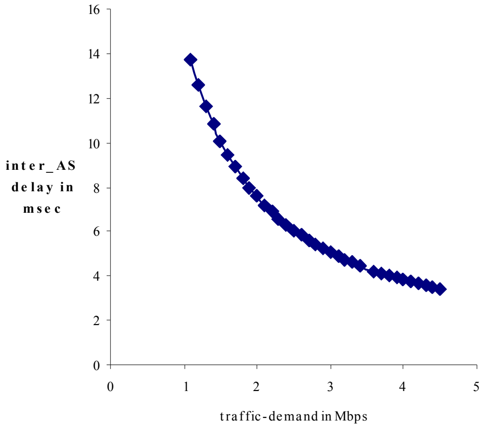

Fig. 3. Overall inter-AS delay

Figure 3 shows the overall inter-AS delay (y-axis) achieved by the integrated optimization strategy as a function of the inter-AS traffic demand (x-axis) for the 4 -node topology shown in figure 2. The shapes of the Figures 3 and 4 follow the piecewise linear delay function. Here importance is given to both intra- and inter-AS delays. Also the objective is to deduce TE solutions that remain overall inter-AS delay near optimal, while significantly improving intra-AS delay and the same objective has been achieved.

The intra-AS TM is the local intra- AS TM with an increasing amount of inter-As traffic.Accrding to Howarth et al [1], the integrated optimization seems to be the best , and produces near optimal solution. Also here the starting solution is an non-optimal one.

Also the best fit for the inter-AS delay and intra-AS delay are determined using Curve Fitting Software [16]. The best fits for inter- and intra- AS delays are given respectively as

$$Y=A*EXP(B*X)/X \tag{11}$$

where

A=0.150508E+02,
B=0.307076E-02
Y=inter-AS delays in msec
X=inter-traffic demand in Mbps

and

$$Y=A*EXP(B*X)/X \tag{12}$$

where

A=0.150669E+02
B=0.201308E-01
Y=intra-AS delays in msec
X= inter-traffic in Mbps.

Equations (11) and (12) shows the best fit for the inter- and intra-AS delays for the 4-node topology shown in figure(2) and for the inter-traffic demand.

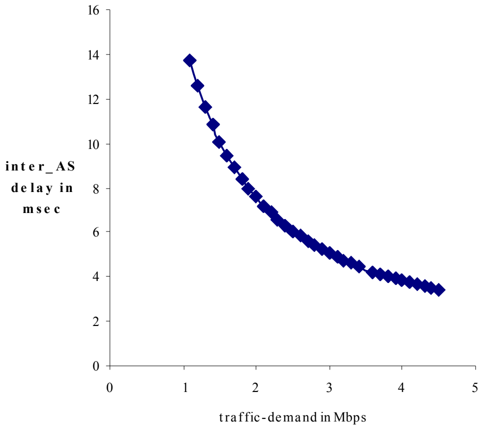

Fig. 4. Overall intra-AS delay

IX. CONCLUSION AND FUTURE WORKS:

This paper formulated a Bi-criteria Latency Optimization model for intra- and inter-AS Traffic Engineering. Also the model shows the interaction effects between intra- and inter-AS Traffic Engineering. Also this work identifies a solution by applying this problem formulation in integrated optimization algorithm discussed and their performances are analyzed for a set of traffic demands for a sample topology. Using the best fits, it is possible to obtain the delay for a particular traffic demand for any type of networks with any no. of Pops, links, OD pairs, inter-AS traffic, intra-AS traffic matrices. This work has a future scope on extending to a dynamic IP environment

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