A Design Algorithm for QoS Network with Flow Delay Control

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***Abstract*—A Mesh Network Topological Optimization and Routing II (MENTOR-II) algorithm is a low complexity and efficient network design algorithm for IP networks with OSPF routing protocol in which appropriate link weights are assigned to the installed links such that the traffic always routes on the path with minimum distance. However, it should be noted that the flow delay of traffic assigned by MENTOR-II are not controlled because MENTOR-II gives the link weights for only assigning traffic flow into the worthy path, therefore routing of traffic flow does not get together with the traffic engineering. This study proposed a new modified version of MENTOR called Q-MENTOR which is able to assign traffic under flow delay controlled. The Q-MENTOR are evaluated in terms of installation cost, routing cost and reliability for 486 network design conditions. The design results are compared with MENTOR-II and it was found that Q-MENTOR is suitable for designing high maximum utilization networks with good delay and reliability. The results also show that low traffic flow delay requirements often present the worst installation cost, routing cost and reliability.**

***Index Terms*—Network Design Algorithm; Traffic Engineering; QoS; MENTOR; MENTOR-II**

I. Introduction

The ultimate goal of network design is to obtain a network that is able to support given traffic demands with the highest performance and lowest cost. The process of Network design is composed of topology design and traffic routing. Topology design is to choose links among network nodes to be installed and determine the link capacity so that the cost to the overall network is minimized. Traffic routing distributes the load for given traffic demands over the installed link such that performances are optimized. Most network design algorithms are fairly complex, such as the simple branch exchange algorithm [1]. It requires a complexity of $O(N^5)$, where N is the number of nodes, which is prohibitive for moderating to large size networks. However, as the Internet becomes the life-line to business and commercial applications, in designing large data networks (i.e. Internet Service Providers (ISPs) backbone) has to be aware of several issues. One of the most important issues is that the IP network is a datagram network, in which the routing protocols route traffic over the path with the shortest distance, i.e. the sum of link weights. However, the link weight setting for an optimum routing pattern is both a complex problem and possibly unfeasible [2], [3]. Ashwin Sridharan [4] explore the trade-off that exists between performance and the overhead associated with the additional configuration steps for IP networks. Mohammed H. Sqalli, Sadiq M. Sait, and Syed Asadullah [5] engineer Tabu Search Iterative heuristic using two different implementation strategies to solve the OSPF weight setting problem for link failure scenarios.

To solve this problem, most ISP backbones implement an overlay approach which will route traffic via Permanent Virtual Connections (PVC) of ATM or Label Switch Paths (LSP) via Multi Protocol Label Switching (MPLS). The benefits of implementing IP traffic engineering with MPLS are discussed by Bernard Fortz and Mikkel Thorup. [6] If IP traffic engineering is not be implemented, some router in the network will result in heavy packet load and service interruptions. Then a better router such as a larger router will be needed. Moreover, the ISPs must be aware of rapid growth and reserve the capacity for the future. Reserved capacity of a network can be controlled by a number of network design parameters, such as the allowable maximum link utilization and the minimum link utilization. For example, setting low allowable maximum link utilization and minimum link utilization often leads to a network with higher cost but more reserved capacity, and vice versa.

II. Related Work

Heuristic network design algorithms called MENTOR (Mesh Network Topological Optimization and Routing) [7] are high-speed and very efficient design algorithms, which select a link to be installed and, at the same time, traffic flows over it is assigned. MENTOR is often used to design virtual circuit packet switching networks such as Frame Relay, ATM and MPLS. However, MENTOR cannot be directly applied to datagram packet switching networks such as purely IP router network. To solve this problem, Cahn et al. [8] proposed a modified version of MENTOR called MENTOR-II in which appropriate link weights are assigned to the installed links, such that the traffic always routes on the path with minimum distance. A. Monsakul and P. Charnkeitkong [9] proposed a modified version of MENTOR-II called M-MENTOR that use T-M algorithm instead of Prim-Dijkstra algorithm to construct backbone spanning tree. This

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algorithm supports both unicast and multicast traffic simultaneously. However, it should be noted that the unicast traffic flows assigned by MENTOR-II and M-MENTOR are limited to only single path routing. After that, K. Jaroenrat and P. Charnkeitkong [10] proposed an enhanced version called E-MENTOR which is able of assigning traffic with the Equal-Cost Multi-Path (ECMP) routing in IP networks.

It is known that delay restriction of selected traffic flow is a subset of Quality of Service (QoS) [11], that is the capability of a network to provide better service to selected traffic. In this study, I proposed new modified versions of MENTOR called QoS MENTOR, or Q-MENTOR, which is able to assign traffic with flow delay control. The Q-MENTOR are evaluated in terms of installation cost, routing cost and reliability for 432 network design conditions. The design results are compared with MENTOR-II.

III. Q-MENTOR CONCEPTUAL

A. Q-MENTOR Algorithm

One limitation of MENTOR-II is that ISP does not consider traffic flow delay requirement between a node pair. However, it is well known from Wille et al. [12] that the new generation of packet switching networks is expected to support real-time multimedia applications which have their own different quality of service (QoS) requirements such as throughput, reliability and delay. This implies that the QoS traffic flow gives networks better performance than the normal traffic flow in MENTOR-II. In this study, a modified version of MENTOR called QoS MENTOR or Q-MENTOR algorithm allows QoS traffic flow of only traffic flow delay in the network.

As with MENTOR and MENTOR-II, Q-MENTOR also starts with node clustering and building a good spanning tree between backbone nodes. Q-MENTOR then follows the procedure described in previous sections, except the third step which is replaced by the following procedure.

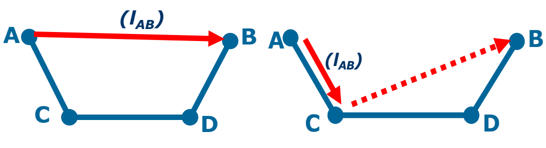

Figure 1. (a) case of $l_{AB} \geq Min_{AB}$ (b) case of $l_{AB} < Min_{AB}$

When you consider whether to add a link A-B:

if l_{AB} (Load requirement from A to B) ≥ Min_{AB} (Minimum acceptable load in A-B)

- Install the direct link if delay of this link is not higher than acceptable flow delay as shown in Fig. 1(a).

- If delay of this link is higher than acceptable flow delay, install multi-link to get acceptable link's delay.

if $l_{AB} < Min_{AB}$.

- Overflow this traffic flow to other nodes if delay between A and B in tree path is not higher than acceptable flow delay as shown in Fig. 1(b).

- If delay between A and B in tree path is higher than acceptable flow delay, install the direct link or multi-link depend on comparison between link's delay and acceptable link's delay as in the case of $l_{AB} \geq Min_{AB}$.

B. Pseudo Code of Q-MENTOR

The K-means clustering algorithm starts with a training data set and a given number of clusters *K*. The samples in the training data set are assigned to a cluster based on a similarity measurement. Euclidean distance is generally used to measure the similarity. The K-means algorithm tries to find an optimal solution by minimizing the square error:

1) Main algorithm

1) Make a good tree by using Prim-Dijkstra's algorithm.
2) Find the order in which to consider node pairs.
3) Select Link to Install and set links' weight with flow delay control.
End .

2) Prim-Dijkstra Algorithm

```
Input: nodes' distance from root(s), Alpha parameter
1) Dist[s] = 0
2) if all nodes are Finished GOTO End.
3) Pick node v in U with the shortest path to s
4) if(Alpha*dist[v1] + length(v1, v2) < dist[v2])
 dist[v2] = Alpha*dist[v1] + length(v1, v2)
 prev[v2] = v1
else GOTO 3)
5) if all edges are finished GOTO 3)
else GOTO 2)
Output: tree structure.
```

3) Link Installation Algorithm with Flow Delay Control.

```
Input: pair[s,d] , load[s-d]
if (load[s-d] > Min.Load)
{
If (Link_Delay(pair[s,d]) > Acceptable_Delay)
 SetWeight(pair[s-d]);
 Install_link(pair[s-d]);
 //Install Single or Multi-Link depend on Traffic Load
else
 SetWeight(pair[s-d]);
 Install_Multi_link(pair[s-d]);
 //Install only Multi-Link because of exceed delay
}
else
{
If (Tree_Path_Delay(pair[s,d]) > Acceptable_Delay)
If (Link_Delay(pair[s,d]) > Acceptable_Delay)
 SetWeight(pair[s-d]);
 Install_Multi_link(pair[s-d]);
 //Install only Multi-Link because of exceed delay
else
 SetWeight(pair[s-d]);
 Install_link(pair[s-d]);
 //Install Single or Multi-Link depend on Traffic Load
else
Overflow(load[s-d]);
}
```

Output: weight[s-d], mesh structure, link's load.

IV. EXPERIMENT

In this paper, I propose Q-MENTOR, which is able to assign acceptable traffic flow delays. The Q-MENTOR is evaluated in term of installation cost, routing cost and reliability for 486 network design conditions. The design results are compared with original MENTOR-II.

In order to evaluate the efficiency of network design calculated by Q-MENTOR algorithm, I analyze the performances of a number synthesized networks and in term of installing cost, routing cost and reliability.

A. Network Generations

In order to evaluate the efficiency of Q-MENTOR algorithms, a numbers of design requirements are generated. A design requirement consists of node distribution and the associated traffic demand matrix. In this study, the networks with 50 nodes is considered by using DELITE [13] to synthesize a set of nodes of randomized location distribution. All node distributions have average node distances of around 800 kilometers and maximum node distance of around 1600 – 1900 kilometers. The traffic demand for each node set is also generated by DELITE with the following assumption:

All nodes have 100 Mbps total traffic in and traffic out.

The traffic between a pair of nodes is inversely proportional to the distance between them.

MENTOR-II is used to generate 162 networks obtained by varying the following design parameters:

$\alpha \in (0, 0.5, 1)$,

$\rho \in (0.4, 0.5, 0.6, 0.7, 0.8, 1.0)$,

$s \in (0, 0.1, 0.2, 0.3, 0.4, 0.5, 0.6, 0.7, 0.8)$

For Q-MENTOR, it used to generate 486 networks by varying additional parameters: flow delay requirement (f) $\in$ (20 µs, 40 µs, 80 µs), where, in this study, it is assumed that full-duplex links of multiple 100 Mbps channels are used in the design process.

B. Network Performances

In order to evaluate the efficiency of Q-MENTOR algorithms, a numbers of design algorithms are evaluated by:

1) - Network Installation Cost

The installation cost of a network G is the sum of all installed link cost as shown in Eq. (1).

$$K = \sum_{a \in A} K_a , \tag{1}$$

where the installation cost of a link is given by Eq. (2).

$$K_a(d_a, n_a) = \omega \, d_a \, n_a , \tag{2}$$

where d_a and n_a are the distance in kilometer and the number of 155 Mbps channels installed on link a, respectively. ω is a cost per kilometer: The default[8] of ω is given as 25. It should be noted that the value of ω can be changed depending on actual cost.

To make the K of network design by different types of MENTOR-II algorithms comparable, the installation cost K of a network G is normalized as in Eq. (3).

$$\Delta K = \frac{K - K_M}{K_M} \times 100 , \tag{3}$$

where K_M is the installation cost of the network design by the original MENTOR-II having the same α, ρ and s as network G.

2) - Routing Cost

Routing cost is used to measure the efficiency of capacity assignment in terms of average network delay. Fortz and Thorup [14] defined the routing cost by sum of link delay (ϕ), but in this paper, I defined the routing cost by average of all link's delay (Eq.(4)) because different design parameter values give the different number of links in the networks.

$$\Phi = \frac{1}{n} \sum_{a \in A} \varphi_a , \tag{4}$$

where ϕ_a is the routing cost of a link a which is derived from link average delay of M/M/1 model as shown in Eq. (5) and n is a number of links in the network.

$$\text{Link delay} = l_a / (c_a - l_a) \tag{5}$$

where c_a and l_a denote the link capacity and the traffic load associated with link $a \in A$.

As with the installation cost, the routing cost Φ of a network G is normalized as in Eq. (6).

$$\Delta\Phi = \frac{\Phi - \Phi_M}{\Phi_M} \times 100 , \tag{6}$$

where Φ_M is the routing cost of the network design by original MENTOR-II having the same α, ρ and s as network G.

3) - Network Reliability

The reliability of a network is obtained by the graph-reduction algorithm proposed by Shooman and Kershenbaum [15] where, in this paper, all link reliability are assumed to be 0.99.

As with the installation cost and routing cost, the reliability R of a network G is normalized as in Eq. (7).

$$\Delta R = \frac{R - R_M}{R_M} \times 100 \tag{7}$$

where R_M is the reliability of the network design by the original MENTOR-II having the same α, ρ and s as network G.

V. PERFORMANCE EVALUATION

A. Installation Cost

For Q-MENTOR networks with α = 0.5 and 1 and low flow delay requirements (f = 20 µs) give the worst average ΔK. Q-MENTOR networks with α = 0, f = 20 µs give the third worst average ΔK and other Q-MENTOR networks give the better average ΔK and close to MENTOR-II network at all maximum utilization.

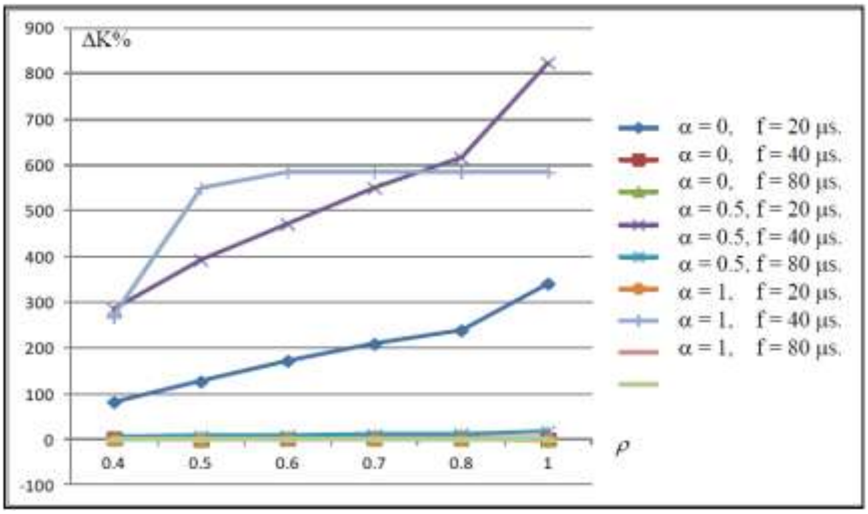

Figure 2. The average ΔK VS. maximum utilization (ρ)

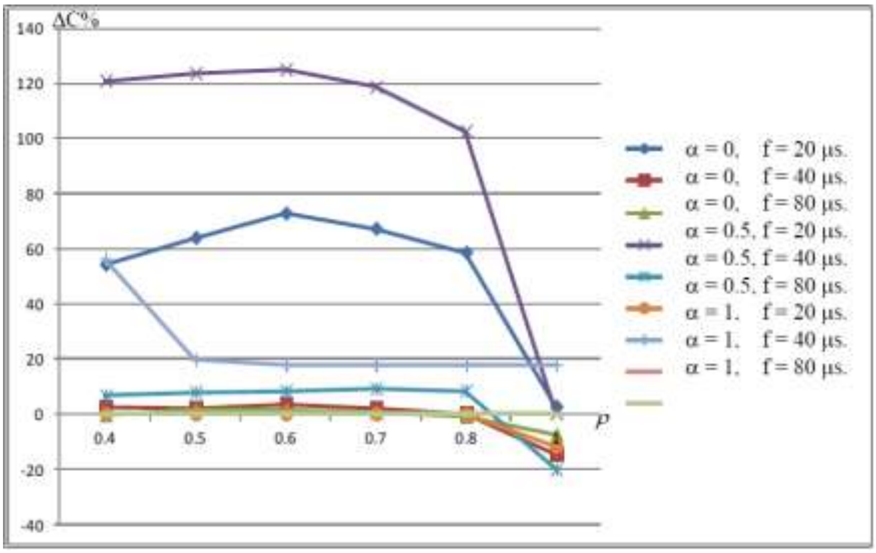

Figure 3. The average $\Delta\Phi$ VS. maximum utilization (ρ)

For all conditions, Q-MENTOR with f = 20 μs gives bad installation cost but MENTOR-II and Q-MENTOR with f = 40 μs and f = 80 μs tend to give good and very close installation cost, but Q-MENTOR with f = 80 μs usually is a bit better than f = 40.

In Fig. (2), network with α = 0, α = 0.5 and α = 1 that have the same maximum utilization, are averaged and plotted versus maximum utilization for each design. As seen from the figure, Q-MENTOR with low flow delay requirements gives a worse performance than MENTOR-II in all conditions. As maximum utilization increase, the average ΔK of all Q-MENTOR network tends to increase.

B. Routing Cost

The experimental results give a design condition that Q-MENTOR with α = 0.5 and low flow delay requirement (f = 20 μs) gives the worst delay performance. The second worst is Q-MENTOR with α = 0 and low flow delay requirement (f = 20 μs) and the third worst is Q-MENTOR with α = 1 and low flow delay requirement (f = 20 μs) Q-MENTOR with medium to high delay requirement (f = 40 - 80 μs) and MENTOR-II, which usually give close delay performance, are usually the best of all.

MENTOR-II almost gives the minimum delay, while Q-MENTOR with low flow delay requirement usually gives the maximum delay. Q-MENTOR with medium to high flow delay requirement tend to give very close delay performance, but Q-MENTOR with high flow delay requirements is usually a bit better and very close to MENTOR-II.

In Fig. (3), networks that have the same maximum utilization are averaged and plotted versus maximum utilization for each design algorithms. As seen from the figure, in almost all conditions, M2 gives the best delay performance except in 100% maximum utilization. The second best are Q-MENTOR with medium to high flow delay requirement which usually gives close delay performance. Finally, Q-MENTOR with low flow delay requirement is usually the worst of all. The average delay of all design algorithms tends to reduce as maximum utilization increase.

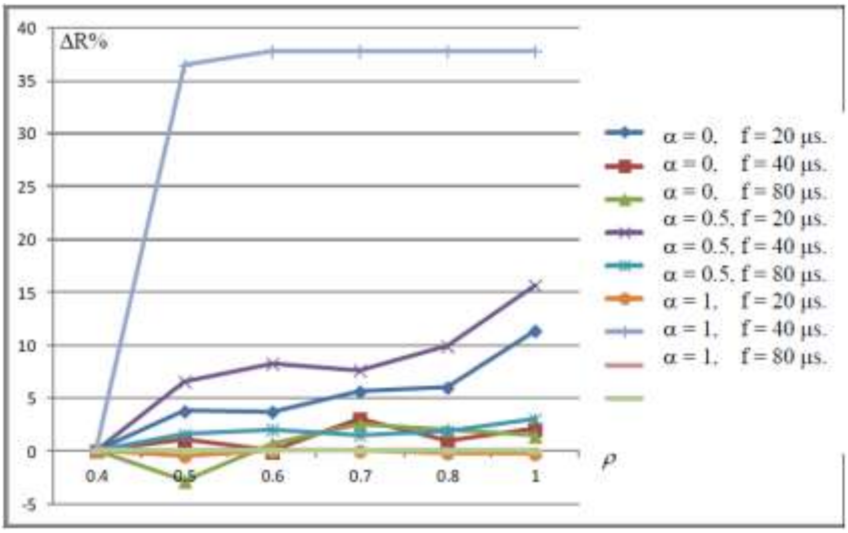

Figure 4. The average ΔR VS. maximum utilization (ρ)

C. Reliability

The experimental result implies that they are nearly close to each other and their reliabilities are almost the same as original MENTOR-II except Q-MENTOR with f = 20 μs which have very high reliability especially when α = 0. Given a design condition, Q-MENTOR with high flow delay requirement (f = 80) and MENTOR-II often give the worst reliability performance. The second worse is Q-MENTOR with medium flow delay requirement (f = 40).

In Fig. (4), the average reliabilities are plotted versus maximum utilization for each design. As seen from the figure, in all utilization conditions, MENTOR-II is among the lowest reliability performance. The networks with low flow delay requirement and low α has the best reliability performance; the second best is the network with low flow delay requirement and medium - high α. Finally, MENTOR-II and the high flow delay requirement network is usually the worst of all, which usually give close performance.

VI. CONCLUSION

This study proposed a newly modified version of MENTOR called QoS MENTOR, or Q-MENTOR, which is able to assign traffic with traffic flow delay requirement. Q-MENTOR is a high speed algorithm with complexity of $O(N^2)$ that is very lower than simple branch exchange algorithm and linear programming method which are $O(N^5)$ or higher in complexity.

Three levels of traffic flow delay (low, medium, high) are used to examine the performance of the algorithm. This Q-MENTOR is evaluated in terms of installation cost, routing cost and reliability for 486 different design conditions. The performance evaluations are compared with the original MENTOR-II.

A. Performance of Q-MENTOR Algorithm

The performance of Q-MENTOR is measured in terms of percentages of differentiation from the original MENTOR-II that has the same design parameters α, ρ and s. It is found that the average gap in installation cost is fairly large. It is 452.17%, 4.50% and 0.068% for 20μs, 40μs and 80μs flow delay requirements, respectively. The average difference of reliability is 16.66%, 1.06% and 0.26% for 20μs 40μs and 80μs flow delay requirements, respectively. The average disparity of routing cost is 58.95%, 1.01% and (- 0.93)% for 20μs 40μs and 80μs flow delay requirements, respectively. The results also show that Q-MENTOR with low flow delay requirements give the worst installation cost and routing cost. On the other hand, Q-MENTOR with low flow delay requirement still gives the best reliability. Q-MENTOR with medium and high flow delay requirement give very close results in all performances, where high flow delay requirement gives slightly better installation cost and routing cost than medium flow delay requirement. In terms of reliability, Q-MENTOR provide improved performance over MENTOR-II. At high maximum utilization, Q-MENTOR gives better average routing costs.

So, we can conclude that Q-MENTOR is suitable for designing high maximum utilization networks with good delay and reliability. Moreover, Q-MENTOR is the heuristic algorithm that has a significantly lower processing time than the traditional methods such as simple branch exchange and linear programming. However The results also show that low traffic flow delay requirement often presents the worst installation cost, routing cost and reliability.

B. Discussion

The three levels of traffic flow delay requirement are used in the performance evaluation: installation cost, routing cost (Delay) and reliability. The design results are compared with those of the original MENTOR-II. The network designed is a static network which assumes that the traffic demand will not be changed or is an average traffic demand. Bernard Fortz, Jennifer Rexford, and Mikkel Thorup [2] proved that IGP weight setting is fairly robust to change in the traffic and topology.

Nowadays, the delay is highest priority for real-time data. However, every version of MENTOR algorithms can indirectly set the delay through the maximum utilization parameter because it directly affects the link's delay (according to the queuing delay of M/M/1 model). The given maximum utilization is a major input parameter which is needed for MENTOR algorithm. Thus, this research can then focus on a way to limit traffic flow delay after the maximum utilization is estimated.

In other words, setting the maximum utilization parameter is indirectly setting each link's delay but it is not a path's delay setting. Then, when considering the traffic flow delay requirement commercially, I chose to give it the first priority rather than the link's delay.

The original idea of this work is the link installation process with delay limited in the path of traffic flow. While a direct link is being installed, the link's delay is being considered. But if the link is not worth to be installed, the path's delay of overflow traffic must be considered. However, since such process is added to the MENTOR algorithm, it might take a bit longer to design a network (very little considered).

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REFERENCES

[1] Aaron Kershenbaum, Telecommunications Network Design Algorithms, *McGraw-Hill*, 1993.

[2] Bernard Fortz, Jennifer Rexford, and Mikkel Thorup, “Traffic engineering with traditional IP routing protocols”, *IEEE Commun. Mag.,* **40** (2002), 118-124.

[3] Walid Ben-Ameur, Eric Gourdin, Benard Liau, Nicolas Michel, “Designing Internet Networks”, *Proc. DRCN2000,* 2000, pp. 56-61.

[4] Ashwin Sridharan, Roch A.Gúerin, and Christophe Diot, “Achieving Near-Optimal Traffic Engineering Solutions for current OSPF/IS-IS Networks”, *TON: IEEE/ACM Trans. on Networking,* **13**(2) (2005), 234-247.

[5] Mohammed H. Sqalli, Sqalli Sait, and Syed Asadullah, “OSPF Weight Setting Optimization for Single Link Failures”, *IJCNC: International Journal of Computer Networks & Communications,* **3**(1) 2011, 168 - 183.

[6] Bernard Fortz and Mikkel Thorup, “Internet traffic engineering by optimizing OSPF weights”, *Proc. IEEE INFOCOM.,* 2000**,** pp. 519–528.

[7] Aaron Kershenbaum, Parviz Kermani, and George A. Grover, “MENTOR: An Algorithm for Mesh Network Topological Optimization and Routing”, *IEEE Trans. Comm.* **39** (1991), 503-513.

[8] Robert S. Cahn, Wide Area Network Design, *Morgan Kaufmann*, 1998.

[9] Annop Monsakul and Pisit Charnkeitkong, “M-MENTOR: a design algorit Enable", *JDCTA: International Journal of Digital Content Technology and its Applications,* **7**(7) 2013, 10 - 20.

[10] Vegesna, Srinivas, "IP Quality of Service for the Internet and the Intranets", *Cisco Press*, 2000.

[11] Emilio C.G. Wille., Marco Mellia, Emilio Leonardi and Marco Ajmone Marsan “Algorithms for IP Network Design with End-to-End QoS Constraints” *The International Journal of Computer and Telecommunications Networking,* **50**(8) 2006, 1086-1103.

[12] Robert S. Cahn, The Design Tool: Delite (software), http://www.mkp.com/wand.htm, 1998.

[13] Bernard Fortz and Mikkel Thorup, “Optimizing OSPF/IS-IS weights in a changing world”, *IEEE Journal on Selected Areas in Communications,* **20**(4) 2002, 756-767.

[14] Andrew M. Shooman and Aaron Kershenbaum, “Exact Graph-Reduction Algorithms for Network Reliability Analysis”, *Proc. GLOBECOM’* 91, 1991, pp. 1412-1420.

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