Enhanced MENTOR Algorithm with ECMP Routing Enable

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Abstract

MENTOR (Mesh Network Topological Optimization and Routing) is an efficient heuristic design algorithm network that assigns traffic flow while selecting links to be installed. MENTOR is suitable to design networks categorized as virtual circuit packet switching such as Frame Relay, ATM and MPLS networks. However, MENTOR cannot be directly applied to datagram packet switching networks such as purely IP router network. This is because the traffic flows determined by original MENTOR are not always the shortest path routing based on IP link weight assignment. To solve this problem, Cahn 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 route on the path with minimum distance. However, it should be noted that the traffic flows assigned by MENTOR-II are limited to a single path routing. This study proposed a new modified version of MENTOR called Enhance-MENTOR, or E-MENTOR, which is able to assign traffic with the Equal Cost Multi-Path (ECMP) routing. Three options of E-MENTOR are considered, i.e. E-MENTOR with single path routing only, E-MENTOR with ECMP routing only and E-MENTOR that consider ECMP routing if benefit. The three options of E-MENTOR are evaluated in term of installation cost, routing cost and reliability for 729 network design conditions. The design results are compared with those of original MENTOR and MENTOR-II.

Keywords: *Network Design Algorithm, Traffic Engineering, Equal Cost Multi-Path Routing*

1. Introduction

The process of Network design is composed of 2 major tasks; first is the topology design and the second is traffic routing. Topology design is necessary to choose links among network nodes to be installed as well as to determine the link capacity so that the cost to the overall network is minimized. Traffic routing, one method of traffic engineering, distributes the load for given traffic demands over the installed link such that performances are optimized. Most network design algorithms are fairly complex [1] [9]. For example simple branch exchange algorithm [9] requires a complexity of $O(N^5)$, where N is number of nodes, which is prohibitive for moderating to large size networks. On the other hand, as the Internet becomes the life-line to business and commercial application, in designing large data network (i.e. Internet Service Providers (ISPs) backbone) has to 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 shortest distance, i.e. sum of link weight. However, the link weight setting for an optimum routing pattern is both a complex problem and possibly unfeasible [3] [7] [4] [15]. To solve this problem, most ISP backbone employ overlay approach which route traffic over Permanent Virtual Connections (PVC) of ATM and recently over Label Switch Paths (LSP) Multi Protocol Label Switching (MPLS). The benefits of implementing IP traffic engineering with MPLS are discussed in [5]. If IP traffic engineering does not be implemented, some router in the network will result in heavy packet losses and service interruption. Then the better router such as the larger router or the multiprocessor router [11] will be needed. Moreover, the ISPs must be aware of the rapid growth traffic demand. Hence enough capacity must be reserved for the future. Reserved capacity of a network can be controlled by a number of network design parameters. Two of the more obvious and easy to understand examples are 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.

Heuristic network design algorithms called MENTOR (Mesh Network Topological Optimization and Routing) [1] is known as high-speed and very efficient design algorithms which selected a link to be installed and, at the same time, traffic flow 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. [2] 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 route on the path with minimum distance. A. Monsakul and P. Charnkeitkong [10] proposed a modified version called M-MENTOR for both unicast and multicast traffic. However, it should be note that the unicast traffic flows assigned by MENTOR-II and M-MENTOR are limited to only single path routing.

It is known that single path routing is a subset of Equal Cost Multipath (ECMP) routing. That is the performance of the network might be improved if ECMP routing is enabled. In this study, we proposed new modified versions of MENTOR called Enhance MENTOR, or E-MENTOR, which is able to assign traffic with the ECMP routing. Three options of E-MENTOR are considered, i.e. E-MENTOR with single path routing only, E-MENTOR with ECMP routing only and E-MENTOR that consider ECMP routing if benefit. The three options of E-MENTOR are evaluated in term of installation cost, routing cost and reliability for 729 network design conditions. The design results are compared with original MENTOR and MENTOR-II.

2. Background

2.1. Overlay Networks Design and Traffic Engineering

Overlay network is incrementally deployed on end-hosts running the overlay protocol software, without cooperation from ISPs. The overlay has no control how packets are routed in the underlying network between two overlay nodes, but it can control, for example, the sequence of overlay nodes, a message traverses before reaching its destination.

Kershenbaum, et al. [1] have proposed a low complexity $O(N^2)$ heuristic network design algorithm called MENTOR (Mesh Network Topological Optimization and Routing). Networks obtained by other known high complexity algorithms are only few percent better than MENTOR networks.

2.2. OSPF Networks Design and Traffic Engineering

Cahn [2] has proposed a low complexity and high efficient heuristic network design algorithm called MENTOR-II which can design an efficient and high-speed MESH Network. Mentor-II permits a system to have at least minimum allowable paths in order to make an effort to assign the traffic flow over the path with the least nodes, installs links with proper utilization, and chooses a high capacity link instead of many low capacity ones to minimize the cost.

MENTOR-II is flexible enough to use as a design algorithm for IP network such as OSPF network that are widely used in the Internet. However, traffic routing of MENTOR-II is not always optimal because Incremental Shortest Path (ISP) Algorithms have reverse consideration of considered paths and may not give the best OSPF weights.

2.3. MENTOR Algorithm

MENTOR algorithm is a low complexity heuristic network design algorithm. This low complexity is achieved by doing implicit routing over a link at the same time it is considered to be installed. For a given set of nodes N, demand matrix D and link cost matrix X, let $d_{s,t}$ and $x_{s,t}$ are the amount of traffic flow and link installation cost from s and t, respectively. The characteristics of network obtained by MENTOR algorithm are (1) traffic demands are routed on relatively direct paths, (2) links have reasonable utilization, and (3) relatively high capacity links are used.

MENTOR starts with clustering process. In this stage, nodes are classified in to end nodes and backbone nodes using a clustering algorithm. Examples of possible clustering algorithms are threshold clustering and K-mean clustering. In this research, we consider only the case where traffic demands are distributed equivalently among all nodes. Therefore, all nodes can be considered as backbone node.

Next, a good tree is formed to interconnect all (backbone) nodes. Kershenbaum, et al. (1991) suggests to a use a heuristic, which can be conceived of as a modification of Prim's and Dijkstra's algorithm to build the tree. The algorithm works in almost the same manner as Dijkstra algorithm but with a tunable parameter α, $0 \leq \alpha \leq 1$. The tree is to be expanded one node at a time by connecting a tree node *i* to an out of tree node *c* such that $\alpha\, d_{mi}+d_{ic}$ minimized, where d_{mi} is the cost of path from the root node along the tree to node *i*. Note that $\alpha = 0$ and 1 is corresponding to Minimum Spanning Tree (MST) and Shortest Path Tree (SPT), respectively.

Given such a tree, the objective of MENTOR is to consider adding a direct link between each pair of nodes if the amount of traffic is reasonable. Let the maximum utilization be ρ, and the minimum utilization be defined in term of ρ and slack s as $(1-s)\,\rho$, where s, $0\leq s \leq 1$. Consider a pair of nodes A and B: let C_{AB} and l_{AB} be link capacity and accumulated load flow between A and B, respectively. If traffic between A and B is too small, i.e $l_{AB} < \rho C_{AB}\,(1-s)$, no link is added and all traffic l_{AB} is overflowed to the next most direct path. A link is added if traffic is in between maximum and minimum utilization, i.e. $\rho\, C_{AB}\,(1\text{-s}) \leq l_{AB} \leq \rho C_{AB}$. However, if $l_{AB} > \rho C_{AB}$, a direct link is added only when traffic bifurcation among multiple routes is possible. If bifurcation is possible, a new link of C_{AB} is added to serve a portion of traffic ρC_{AB}, and the left portion $l_{AB} - \rho C_{AB}$ is overflowed to the next most direct. Otherwise, if no bifurcation is possible, no link is added and all traffic l_{AB} is overflowed to the next most direct path.

2.4. MENTOR-II Algorithm

MENTOR-II [2] is similar to MENTOR but while considering a direct link to serve traffic demand between 2 end nodes, it calculated an appropriate link cost for the direct link based on Incremental Shortest Path (ISP) algorithm so that OSPF/IS-IS routers always direct traffic through a desired single shortest path route. The concepts of MENTOR-II and ISP algorithm can be described as follows:

- At start, set the weight for each link in the spanning tree to the installation cost of the link.
- Let $d_{spt}(A,B)$ be the shortest path distance between node A and B through the selected spanning tree, consider adding a direct link between each nodes pair in the decreasing order of $d_{spt}(\cdot)$.
- When consider whether to add a link L_{AB} between A and B, the weight W_{AB} of L_{AB} is initially set to a reasonably high value. ISP then tries to draw traffic flow through L_{AB} as much as possible by lowering the W_{AB}. A constraint is that the link W_{AB} should be greater or equal to the installation cost.
- L_{AB} is added if we can find an eligible value of W_{AB} and the amount of traffic flow though it falls in the reasonable zone defined by ρ, C_{AB}, and s.

When MENTOR-II considers all possible direct links, all links are assigned with appropriate link weights which ensure the shortest path routing.

3. E-MENTOR Conceptual

3.1. E-MENTOR Algorithm

One limitation of MENTOR-II is that ISP considers only single shortest path routing between a node pair. However, it is well known from [5], [7] that single path routing is a subset of ECMP routing. This implies that the design algorithm with ECMP routing enable might give networks with better performance than the one that allow only single path routing like MENTOR-II. In this study, we proposed a modified version of MENTOR called ECMP MENTOR or E-MENTOR algorithm which allows ECMP routing in the network.

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

When consider whether to add a link L_{AB}, both of ECMP routing and single path routing must be examined.

- If ECMP routing is chosen, the w_{AB} is set to d_{spt}(A,B).
- If single path routing is chosen.
  - Set w_{AB} to a value that is less than d_{spt}(A,B).
  - If necessary decrease the weight of the direct links that have been installed before in order to control the traffic flow as desired.
- The above statement does not specify how to choose between single path routing and ECMP routing. In this study, three versions of E-MENTOR are considered.
- E-SP is a version of E-MENTOR in which single path routing option is always chosen.
- E-MP is a version of E-MENTOR in which ECMP routing option is always chosen.
- E-S/MP is a version of E-MENTOR in which both single path routing and ECMP routing are examined, and the one that minimizes the installation cost is chosen.

It should be note that if ECMP routing for traffic in one direction, e.g. from A to B, is examined, the traffic flow in the reverse direction (i.e. from B to A) might not mirror the one in the forward direction. In this case, additional capacity and hence the installation cost might be required. To avoid this problem, no more than one ECMP traffic is allow to terminating to each node.

3.1.1. Enhanced MENTOR algorithm without Flow Split

MENTOR-II Algorithm is a network design algorithm which gives weight to make the traffic flow in the designated paths using Incremental Shortest Path Algorithm. One disadvantage is that the flow cannot be reversed; therefore, the given weights are not always optimal. For better efficiency of the network, this MENTOR algorithm without flow split needs to be improved such that the assigned weights can be modified.

3.1.2. Enhanced MENTOR algorithm with ECMP

This improved MENTOR algorithm allows a network to be equal split. The installation of a direct link between a node pair depends on whether there is enough link utilization. The two cases are 1) the link will be installed and responsible for all the traffic if the utilization is between the minimum and maximum, and 2) the link will also be installed but responsible for only half of the traffic while letting the other half overflow in the Shortest Path Tree if only half of the utilization is between the minimum and maximum. If both cases are possible, the overall cost will be compared, and lower one will be chosen.

3.2. Pseudo Code of E-MENTOR

<u>Main algorithm</u>

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 (E-SP or E-MP or E-SP/MP) and set links' weight with reverse links' weight set algorithm.

End .

<u>Prim-Dijkstra algorithm</u>

```
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.
```

Reverse links' weight set algorithm.

```
Input:  node pair[s,d], load[s-d], ECMP link[pair[s-d]]
if (load[s-d] > Min.Load)
    if(ECMP link[pair[s-d] == true)
        SetWeightECMP(pair[s,d];
        Install_ECMP_link(pair[s-d]);   //ECMP=Multi Path
    else
        SetWeightSP(pair[s-d]);
        Install_SP_link(pair[s-d]);                //SP = Single Path
else Overflow(load[s-d]);                          //No link installed
Output: weight[s-d].
```

Function SetWeightECMP(pair[s-d]) //Equal Path

```
weight[pair[s-d]] = TreeDistance[pair[s-d]];
```

Function SetWeightSP(pair[s-d]) //Single Path

```
weight[pair[s-d]] = TreeDistance[pair[s-d]]-1;
for each node pair[a-b] of all node pair
    if(pair[s-d]is subtree of pair[a-b] && link[a-b] was installed)
        UpdateWeight(pair[a-b]);
```

Function UpdateWeight(pair[a-b])

```
weight[pair[a-b]]--;
for each node pair[x-y] of all node pair
    if(pair[a-b]is subtree of pair[x-y] && link[x-y] was installed)
    UpdateWeight(pair[x-y]);
```

4. Experiment

In this paper, I propose a new modified version of MENTOR called Enhanced MENTOR, or E-MENTOR, which is able to assign traffic with the ECMP routing. Three options of E-MENTOR are considered, i.e. E-MENTOR with single path routing only, E-MENTOR with ECMP routing only and E-MENTOR that consider ECMP routing if a benefit can be measured. The three options of E-MENTOR are evaluated in term of installation cost, routing cost and reliability for 729 network design conditions. The design results are compared with original MENTOR and MENTOR-II.

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

4.1. Network Generations

In order to evaluate the efficiency of E-MENTOR algorithms, a numbers of design requirements are generated. A design requirement composes of node distribution and the associated traffic demand matrix. In this study, three groups of networks with different number of nodes, i.e. 10, 25 and 50 nodes are considered. For each group, DELITE [6] is used to synthesize 3 sets of nodes of different location distribution which are obtained by randomly varying SEED parameter of DELITE. 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 following assumption:

- All nodes have the same the total traffic in and traffic out.
- The traffic between a pair of node is inverse proportional to the distance between them.

For each set of nodes, three levels of traffic in and out, i.e. 100, 150 and 200 Mbps are considered. Hence, for a given number of nodes, there are totally 9 requirements which are permutation of 3 different node distributions and 3 different traffic loads.

For a group of three requirements having the same number of node and traffic load, each of MENTOR, MENTOR-II and three versions of E-MENTOR are used to generate 81 networks obtained by varying the following design parameters:

$\alpha \in (0, 0.5, 1)$,
$\rho \in (0.2, 0.4, 0.6)$,
$s \in (0.2, 0.5, 0.8)$

Where, in this study, it is assumed that full-duplex links of multiple 155 Mbps channels are used in the design process.

4.2. Network Performances

The efficiencies of each designed networks are algorithms are evaluated by:

4.2.1. Network Installation Cost

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The installation cost of a network *G* is the sum of all installed link cost

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

where the installation cost of a link is given by

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

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 of ω is given as 25 [2]. 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 algorithms comparable, the installation cost K of a network *G* is normalized as follows

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

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

4.2.2. Routing Cost

Routing cost is used to measure the efficiency of capacity assignment in term average network delay. Fortz and Thorup [14] defined the routing cost by

$$\Phi = \sum_{a \in A} \phi_a, \tag{4}$$

where ϕ_a is the routing cost of a link *a* which is derived from link average delay of M/M/1 model.

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

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 follows

$$\Delta\Phi = \frac{\Phi - \Phi_M}{\Phi_M} \times 100, \quad (6)$$

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

4.2.3. Network Reliability

The reliability of a network is obtained by graph-reduction algorithm proposed by Shooman and Kershenbaum [8] 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 follows

$$\Delta R = \frac{R - R_M}{R_M} \times 100, \quad (7)$$

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

5. Performance Evaluation

5.1. Installation Cost

For 10 node networks, E-MP and M2 algorithms give the best and the second best average ΔK at all traffic loads. For 25 node networks, E-MP and E-S/MP algorithms give the best and the second best average ΔK at all traffic loads. For 50 node networks, E-S/MP and E-SP give the best and the second best average ΔK at all traffic loads.

For all conditions, E-MP always gives bad installation cost. E-SP and E-S/M tend to give good and very close installation cost, but E-S/MP usually is a bit better.

In Figure 1, 10, 25 and 50 nodes network that have the same traffic load, are averaged and plot versus traffic load for each design algorithms. As seen from the figure, three types of E-SP, E-MP and E-S/MP give better performance than M2 in all traffic load conditions. As traffic load increase, the average ΔK of E-SP, E-MP and E-S/MP tend to increase a little bit.

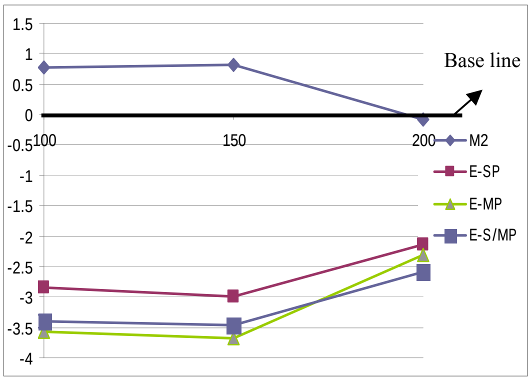

Fig. 1. The average ΔK VS. Traffic Load

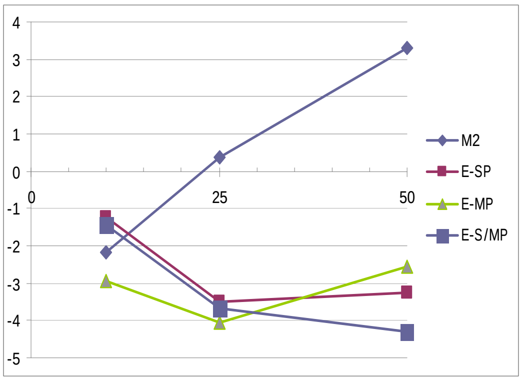

Fig. 2. The average ΔK VS. Number of nodes

On the other hand, different traffic load that have the same number of network node are also averaged and plot versus the number of node for each design algorithms in Figure 2. For 10 node network, E-SP and E-S/MP give a bit worse performance than M2 while E-MP gives the best performance. As the number of node increase, the performance of all E-SP, E-MP and E-S/MP improve while that of M2 gets worse.

5.2. Routing Cost

The experiment result give a design condition that M2 gives the best delay performance. The second best are E-SP and E-S/MP which usually gives close delay performance. And E-MP is usually the worst of all.

In most conditions, M2 gives the minimum delay, while E-MP usually gives the maximum delay. E-SP and E-S/MP tend to give very close delay performance, but E-S/MP is usually a bit better.

In Figure 3, 10, 25 and 50 nodes network that have the same traffic load, are averaged and plot versus traffic load for each design algorithms. As seen from the figure, in all traffic load conditions, M2 give the best delay performance. The second best are E-SP and E-S/MP which usually gives close delay performance. Finally, E-MP is usually the worst of all. The average delay of all design algorithms tend to increase as traffic load increase.

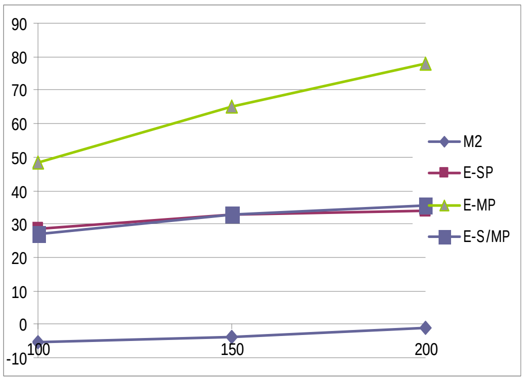

Fig. 3. The average ΔΦ VS. Traffic Load

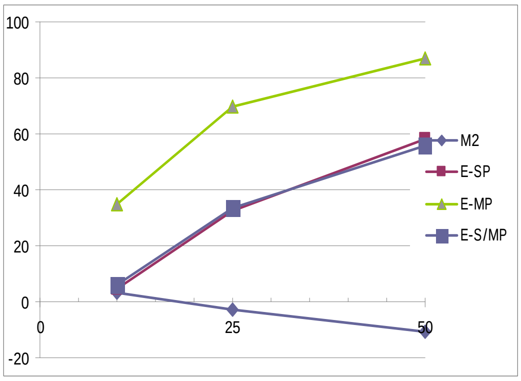

Fig. 4. The average ΔΦ VS. Number of nodes

On the other hand, different traffic load that have the number of network node are also averaged and plot versus the number of node for each design algorithms in Figure 4. As the number of node increase, the performance of M2 improves while those of E-SP, E-MP and E-S/MP get worse.

5.3. Reliability

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The experiment result implies that they are very close to each others and their reliabilities are almost the same as original MENTOR. Given a design condition, M2 always gives the best reliability performance. The second best are E-SP and E-S/MP which usually gives close delay performance. E-MP is usually the worst of all.

In Figure 5, the average reliabilities are plot versus traffic load for each design algorithms. As seen from the figure, in all traffic load conditions, M2 give the best reliability performance. The second best are E-SP and E-S/MP which usually gives close performance. Finally, E-MP is usually the worst of all. The average reliabilities of all design algorithms tend to close to each other as traffic load increase.

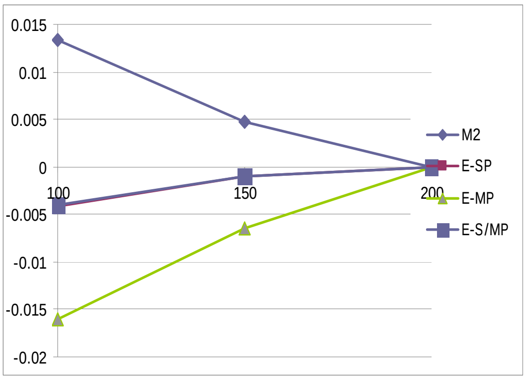

Fig. 5. The average Δ*R* VS. Traffic Load

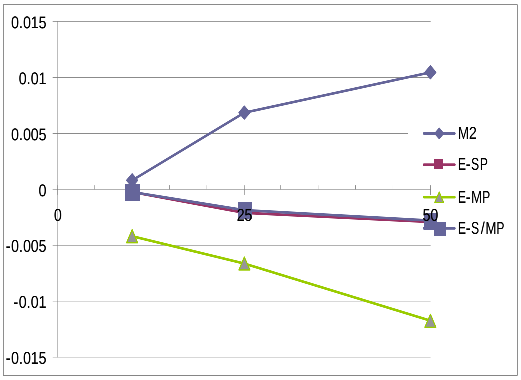

Fig. 6. The average Δ*R* VS. Number of nodes

On the other hand, different traffic load that have the number of network node are also averaged and plot versus the number of node for each design algorithms in Figure 6. As the number of node increase, the performance of E-SP, E-MP and E-S/MP get worse while that of M2 improves.

6. Conclusion

This study proposed a newly modified version of MENTOR called Enhanced MENTOR, or E-MENTOR, which is able to assign traffic with the Equal Cost Multi-Path (ECMP) routing. Three approaches of E-MENTOR are considered: E-SP with single path routing only, E-MP with ECMP routing only, and E-S/MP that consider ECMP routing if beneficial. The three options of E-MENTOR are evaluated in terms of installation cost, routing cost and reliability for 729 different design conditions. The performance evaluations are compared with the original MENTOR.

6.1. Performance of E-MENTOR Algorithm

The performances of M2, E-SP, E-MP and E-S/MP are measured in terms of percentages of differentiation from the original MENTOR that has the same design parameters α, ρ and s. It is found that the average difference of installation cost is in a range of - 10 and 10 percent. The average gap in routing cost is fairly large. Its range is within -10 and 160 percent. The average disparity of reliability is moderate and range between - 0.01 and 0.03 percent. The results also show that M2 gives the worst installation cost. On the other hand, M2 still gives the best routing cost and reliability. E-SP and E-S/MP give very close results in all performances, where E-S/MP is slightly better than E-SP. In terms of installation cost, E-SP and E-S/MP provide improved performance over M2. At low traffic load and/or small number of nodes, E-MP gives the best average installation cost. However, E-SP and E-S/MP outperform E-MP as the traffic load and/or the number of node increase. The results also show that E-MP often presents the worst routing cost and reliability.

6.2. Discussion

The three options of Enhanced MENTOR are evaluated in term of installation cost, routing cost (Delay) and reliability. The design results are compared with those of original MENTOR and 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. A research [3] has proved that IGP weight setting is fairly robust to change in the traffic and topology.

Nowadays, the delay is higher priority than installation cost for designing network. However, every version of MENTOR algorithms can indirectly set the delay through the maximum utilization parameter because it directly affects the delay (according to the queuing delay of M/M/1 model). The given maximum utilization is major input parameter which is needed for MENTOR algorithm. Thus, this research can then focus on the way to reduce the installation cost after the maximum utilization is estimated, and the delay is known.

In the other word, setting the maximum utilization parameter is indirectly setting the delay to be at a certain point and also makes the consideration about the installation cost interesting. Moreover, when considering the installation cost commercially, I chose to give it the first priority rather than the delay.

The original idea of this work is the process of setting link weight with a reverse update of Enhanced MENTOR algorithm. While a link is being installed, the weight of the previously installed link will be checked and updated which makes it possible to design an IP network and also allows ECMP routing with a low installation cost. However, since such process is added to MENTOR algorithm, it might take a bit longer time to design a network (very little considered).

6.3. Summary

The benefit of E-MENTOR algorithm is that:

- The average installation cost is lower than that of a network designed with MENTOR-I while the installation cost of a network designed with MENTOR-II algorithm is higher than that of a network designed with MENTOR.

Some drawbacks are:

- The routing cost (Delay) is averagely higher than that of a network designed with MENTOR algorithm while the routing cost of a network designed with MENTOR-II algorithm is averagely a bit less than that of a network designed with MENTOR.
- The reliability is averagely about the same, i.e. E-MENTOR algorithm is a bit less reliable than MENTOR algorithm while MENTOR-II algorithm is a bit more reliable than MENTOR algorithm.

The result of this research is a new alternative IP network design algorithm with ECMP routing capability and lower installation cost which is more beneficial comparing to higher routing cost.

6.4. Future Work

Extension of the work in this research could take place along two directions. The first would be in identifying a new heuristic design algorithm that concerns routing of both unicast and multicast traffic. The second direction could be in improving of IP network design algorithm according to end-to-end QoS requirements [12] or using Bandwidth-Cost based QoS Extension to the routing protocol [13]. This enables the new generation of packet-switching networks to support a wide range of communication-intensive real time multimedia applications.

7. References

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