M-MENTOR: A Design Algorithm for IP Networks with Mixed Traffic

ANNOP MONSAKUL
annop@tapee.ac.th
Faculty of Information Technology
Rangsit University
Pathumtani, THAILAND

PISIT CHARNKEITKONG
pisitcha@pit.ac.th
Faculty of Science and Technology
Panyapiwat Institute of Technology
Nonthaburi, THAILAND

Abstract: The design of IP networks to support traffic engineering for both unicast and multicast traffic is a very difficult problem. This paper proposes a heuristic design algorithm called M-MENTOR that concern routing of both types of traffic. However, since multicast traffic model could be employed in many situations and could be managed by various kinds of multicast routing protocols, this paper consider only the design process of the IP networks with following features: (1) network of within the same Autonomous System (AS), (2) routing protocol support multiple weight on each link, (3) the multicast traffic from different sources share the same multicast tree. The efficiency of M-MENTOR is evaluated for various traffic demands and networks of 10, 30 and 50 node and compared with MENTOR-II. The experimental results show that, in almost all cases, M-MENTOR give better performance in term of installation cost.

Key-Words: - IP Network Design, MENTOR Algorithm, Unicast/Multicast Traffic, Traffic Engineering

1 Introduction

IP network design that concern both unicast and multicast routing is a very difficult problem. The problem is even more difficult if we chose mange the traffic by appropriate weight setting of links in the OSPF protocol instead of using the overlay network technique. These kinds of problems are classified as "Mixed Integer Linear Programming" or MIP [1].

To reduce complexity of the network design process Kershenbaum et al. [2] has developed a complexity heuristic algorithm with low called MENTOR (Mesh Network Topological Optimization and Routing). The networks designed by MENTOR give very good performance that very close to that of the optimum [3][4]. MENTOR also can be used to design virtual circuits packet switching network such as ATM or Frame Relay. However, a MENTOR algorithm can not be used directly to design routers or MPLS routers networks that employ OSPF or IS-IS routing protocol. This is because MENTOR does not perform appropriate link weight setting. Cahn [5] has improved the MENTOR algorithm such that appropriate OSPF link weight can be set during the design process using Incremental Shortest Path (ISP). Such algorithm is known as the MENTOR-II. However, it should be note that almost all the above design algorithms have been developed for network with only unicast traffic.

Presently, several important emerging multicast applications such as distributed database systems, radio, television, video conferencing system, distance learning system, are becoming more and more popular. As a result, the portion of multicast traffic on the IP network in almost all organization is increasing rapidly. Therefore, IP network design process should also effectively route multicast traffic in addition to the traditional unicast traffic.

The efficient IP networks design processes for multicast traffic should to consider the traffic traversing paths and routing protocols. For multicast traffic, it is well known that the optimum spanning tree that connects the transmitter and all its receivers is called Steiner Tree. Unfortunately, there is no known algorithm that can be used to systematically construct the Steiner Tree. Today, most Steiner trees are obtained by heuristic algorithm. One of the best known heuristic for Steiner is T-M algorithm that was proposed by Takahashi and Matsuyama [6]. An interesting modification of T-M algorithm has been proposed by Maxemchuk [10] which is optimized for multi speed multicast systems.

There are many choices for multicast routing protocols. But, one of the most popular used within an Autonomous System (AS) is Protocol Independent Multicast (PIM). PIM also has several modes depend upon the density or the number of receivers within the area. PIM-Dense Mode (DM) is for the case of high receiver density. PIM-Any Source Multicast (ASM) is for the case of low receiver density and there are few numbers of transmitters, e.g. few-to-many. PIM-Source Specific Multicast (SSM) is for the case single transmitter, e.g. one-to-many. PIM-Bider (Bidirectional) is for the case that there are many receivers and transmitters (Many-to-many). PIM-DM is now obsolete. The most popular option may be PIM-ASM because it supports both PIM-DM and PIM-SSM modes. However, PIM-Bider is seemed to be the most efficient because transmitters share the same multicast tree. With shared multicast trees, the routers do not have to remember different tree for each transmitter.

The problem of PIM is that, it uses the link weight based Shortest Path Tree to distribute the traffic. Theoretically, this Shortest Path Trees are not necessary Steiner Trees which are more favorable for multicast operation.

To improve routing performance for mixed unicast and multicast traffic Wang and Pavlou [7] proposed to separate the flow management of unicast and multicast traffic by employing a newly proposed Interior Gateway Routing Protocol (IGP) that support multiple sets of link weights called Multitopology Enable IGP (MT-IGP) Multitopology extension to ISIS (M-ISIS) [8] and Multitopology extension to OSPF (M-OSPF) [9]. However, Wang and Pavlou [7] have not yet discussed about the network design process for mixed unicast and multicast traffic.

This study proposes a heuristic design algorithm for IP networks with mixed unicast and multicast traffic called M-MENTOR. The algorithm is obtained by modifying spanning tree building portion of MENTOR-II. M-MENTOR used modified T-M algorithm to construct core spanning tree instead of Prim-Dijkstra algorithm. Therefore, M-MENTOR is focus on design of IP networks with following features: (1) all network members are within the same AS, (2) the employ routing protocol should support multiple link weight such as M-OSPF and M-ISIS, (3) the multicast traffic from different sources share the same multicast tree. e.g. PIM-Bidir is deployed. The performances of networks design by M-MENTOR are evaluated in term of installation cost and compared with the networks design by original MENTOR-II for various traffic demands and networks with different number of nodes. The experimental results show that, in almost all cases, M-MENTOR gives better performance in term of installation cost.

2 Backgrounds

2.1 MENTOR Algorithm

MENTOR algorithm [2] 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 properties 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. Here in this paper, 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. [2] suggests to a use a heuristic, which can be thought of as a modification of Prim and Dijkstra algorithm to build the tree. The algorithm works almost the same manner as Dijkstra algorithm but with a tunable parameter α, $0 \le \alpha \le 1$. The tree is to be expanded one node at a time by connecting a tree node i to an out of tree node j such that $\alpha L_i + x_{ic}$ minimized, where L_i is the cost of path from 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 a tree, the objective of MENTOR is to 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, $0 \le s \le 1$. 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. $\rho\, C_{AB}\, (1-s) \le l_{AB} \le \rho C_{AB}$. 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 $\rho\, C_{AB}$, and the left portion $l_{AB} - \rho\, C_{AB}$ is overflowed to the next most direct path. Otherwise, if no bifurcation is possible, no link is added and all traffic l_{AB} is overflowed to the next most direct path.

2.2 MENTOR II Algorithm

MENTOR-II [2] also starts with node clustering and building a good spanning tree between backbone nodes. But when MENTOR-II consider adding a direct link to serve traffic demand between a pair of nodes, at the same time, calculates an appropriate link weight for the each link based on Incremental Shortest Path (ISP) algorithm. The concepts of MENTOR-II and ISP algorithm can be described as follows:

1) At start, set the weight for each link in the spanning tree to the installation cost of the link.

2) Let d_{spt}(A,B) be the shortest path distance between node A and B through the selected good spanning tree, consider adding a direct link between each nodes pair in the decreasing order of $d_{spt}(\cdot)$.
3) 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.
4) 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.

2.3 The Steiner Tree and T-M Heuristic

Given a directional graph $G(E,V)$, let $S \subseteq V$ be a set of nodes involved in multicast communication. Our objective is to construct a minimum cost tree interconnecting all members of *S*. The member of the tree may include some node $n \notin V$. but $n \in S$. In this study, the cost of a link is an increasing function of the bandwidth and the length of the link, and not dependent upon the utilization or availability of the link. Such problem is called Steiner tree problem. A special case is when $S \equiv V$, Steiner tree is equivalent to Minimum Spanning Tree (MST). However, unlike MST problem, there is no systematic algorithm that provides best solution for Steiner tree problem.

T–M Heuristic algorithm: One of the best known heuristic forf Steiner problem is T–M algorithm [6]. The algorithm operates in a manner that is similar to Prim's algorithm for MST. At each step a receiver is added to the tree. The receiver that is added has the shortest path between itself and the currently existing tree, just as the node that is added in the algorithm has the shortest path. The difference between the two procedures is that the path in the algorithm is a single link, allowing a straight forward search, while the path in the T–M heuristic algorithm may contain several links.

Modified T–M Heuristic algorithm: An important difference between the problem of multicasting and the conventional Steiner tree problem is that the cost of a link is not fixed but depends upon the maximum rate of the receivers that share the path. To solve this problem Maxemchuk [10] has proposed a heuristic called Modified T-M algorithm. In Modified T-M algorithm, we first form a Steiner tree with a high rate set of receivers and then successively add lower rate sets of receivers to that tree with the same procedure as for the higher rate set.

3 M-MENTOR Algorithm

From the principles outlined in the previous section, we propose a modified MENTOR-II algorithm, called M-MENTOR algorithm, for IP networks with following features:

(1) All network members are within the same AS,

(2) The employ routing protocol should support multiple link weight such as M-OSPF and M-ISIS,

(3) The multicast traffic from different source share the same multicast tree. e.g. PIM-Bidir is deployed.

M-MENTOR starts with node clustering and select the backbone nodes in the same way as MENTOR and MENTOR-II.

Next, since all multicast transmitters share the same tree to distribute the data, instead of building Prim-Dijkstra tree, the backbone spanning tree is build based on Modified T-M algorithm. The algorithm forms a Steiner tree with a high rate set of receivers and then successively adds lower rate sets of receivers to the tree and, finally, adds nodes without receiver (zero rate receivers) to the tree. To guide the multicast traffic to flow only through the core spanning tree the multicast link weight should be set appropriately. One simple solution is to set the multicast link weight of all links in the spanning tree to 1 and that of the others to very large number.

After we obtained a Steiner tree, direct links are added and their unicast link weights are determined based on the unicast traffic in exactly the same way as in MENTOR-II.

The capacity a link on the tree is determined by the sum of its own unicast traffic, the overflow unicast traffic from other routes and the multicast traffic that flow through it.

4 Design Example

4.1 Requirements

An organization network composes of 6 backbone nodes shown in Figure 1. The network must support both unicast and multicast traffic. Table 1 and Table 2 show the multicast and unicast traffic demands between backbone nodes in the network. Table 3 shows the installation cost of link with 64 Kbps capacity. It is decided that the reasonable range of link utilization is determined by $\rho = 0.5$ and slack $s = 0.4$

Table 1: Multicast traffic between backbone nodes

S\R	N1	N2	N3	N4	N5	N6
N1	-	256	-	128	128	256
N2	256	-	-	128	128	256
N3	-	-	-	-	-	-
N4	128	128	-	-	128	128
N5	128	128	-	128	-	-
N6	256	256	-	128	128	-

Unit: Kbps

Table 2: Uniicast traffic between backbone nodes

S\D	N1	N2	N3	N4	N5	N6
N1		6120	1421	684	3472	5302
N2	6120		10849	685	3629	4717
N3	1421	10849		990	5863	4878
N4	684	685	990		7267	5376
N5	3742	3629	5863	7267		24747
N6	5302	4717	4878	5376	24747	

Unit: bps

Table 3: 64 Kbps Channel Link Installation Cost

S\D	N1	N2	N3	N4	N5	N6
N1	500	5905	8255	6915	6720	5740
N2	5905	500	7955	8385	7960	7900
N3	8255	7955	500	3185	2720	3985
N4	6915	8385	3185	500	1160	1710
N5	6720	7960	2720	1160	500	1800
N6	5740	7900	3985	1710	1800	500

4.2 Steiner Tree Construction

From Table 1, the backbone node can be classified into 3 groups based on capacity of the receiver, e.g. 256, 128 and 0 Kbps (no receiver), as follows.

G_{256} = {N1, N2, N6}
G_{128} = {N4, N5}
G_0 = {N6}

M-MENTOR first constructs a Steiner tree to interconnect members of G_{256}, i.e. N1, N2 and N6. At this stage, the installed links are N1-N2 and N1-N6 Next members of G_{128}, i.e. N4, N5, are connected to the tree with N4-N6 and N4-N5. Finally, member of G_0, i.e. N6, is connected to the tree with N3-N5.

4.3 Multicast Traffic

In this study we assume that each transmitter open one different multicast session that cannot be mixed with other session.

Consider N1-N2 link, N2 may receive 2 of 256 Kbps multicast sessions and 2 of 128 Kbps multicast sessions simultaneously. Thus total multicast traffic on N1-N2 direction is 768 Kbps. On the other hand, N2-N1, N1 may receive one of 256 Kbps multicast session.

Consider N6-N1 link, N1 may receive 1 of 256 Kbps multicast and 2 of 128 Kbps multicast sessions simultaneously. Thus total multicast traffic on N6-N1 direction is 512 Kbps. On the other hand, N1-N6, N6 may receive 2 of 256 Kbps multicast session simultaneously. Thus total multicast traffic on N1-N6 direction is 512 Kbps.

Consider N4-N6 link, N6 may receive 2 of 128 Kbps multicast sessions simultaneously. Thus total multicast traffic on N4-N6 direction is 256 Kbps. On the other hand, N6-N4, N4 may receive 3 of 128 Kbps multicast sessions simultaneously. Thus total multicast traffic on N1-N6 direction is 384 Kbps.

Consider N5-N4 link, N4 may receive 1 of 128 Kbps multicast session. On the other hand, N4-N5, N5 may receive 4 of 128 Kbps multicast sessions simultaneously. Thus total multicast traffic on N1-N6 direction is 512 Kbps.

According to Table 1 there is no multicast traffic on N3-N5 link.

4.4 Overall Traffic and Design Results

Using ISP algorithm as in MENTOR-II, 2 new direct links N2-N5 and N5-N6 are installed for unicast traffic. Figure 1 and Table 4 show the final design result obtained by M-MENTOR. In Table 4, “weight” is the unicast weight of the link obtained by ISP algorithm; “load” is the total traffic on each direction of the link; “# Chan” is the number of 64 Kbps channels of the link. Traffic load on each direction may compose of unicast and multicast traffic. If available, the number represented the amount of multicast traffic is underlined.

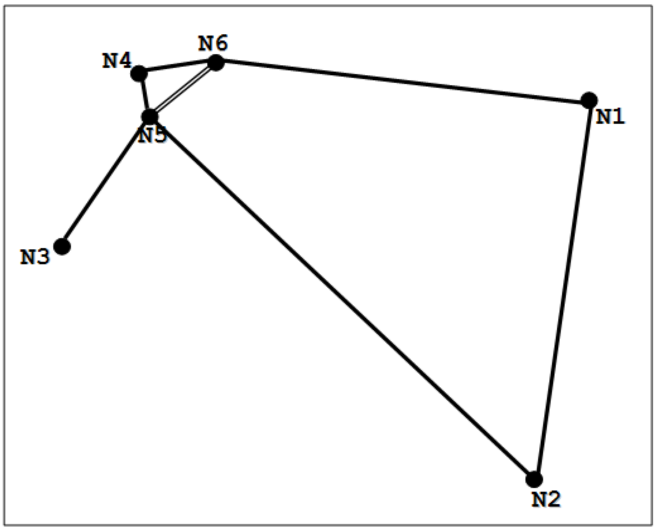

Figure 1 : Network Design Result

Table 4: M-MENTOR Design Results

Link	s_i,d_i	weight (unicast)	Load (bps)	# Chan
1	N1,N2 N2,N1	5,905	6,120+768,000 (6,120+256,000)	25
2	N1,N6 N6,N1	5,740	10,879+512,000 (10,879+512,000)	17
3	N4,N6 N6,N4	1,710	6,060+256,000 (6,060+384,000)	13
4	N4,N5 N5,N4	1,160	8,942+512,000 (8,942+128,000)	17
5	N5,N3 N3,N5	2,720	24,001 (24,001)	1
6	N2,N5 N5,N2	8,774	19,880 (19,880)	1
7	N5,N6 N6,N5	2,869	39,235 (39,235)	2

5 Performance Evaluation

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

5.1 Requirement Generation

To evaluate the efficiency of M-MENTOR algorithms for different sizes, three design requirements of 10, 30 and 50 nodes are generated. A design requirement composes of node distribution and the associated traffic demand matrix. For each requirement, a design tool called DELITE [5] is used to synthesize nodes location distribution which is 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 unicast traffic demand for each requirement is also generated by DELITE with following assumption:

1) All nodes have the same total unicast traffic in and total unicast traffic out. In this study, the total unicast traffic in and out of 256, 512, 1024, 2048, 3072 and 4096 Kbps are considered
2) The unicast traffic between a pair of node is inverse proportional to the distance between them.

In this study we assume that a link interconnecting a pair of nodes could be installed with multiple communication channel of bandwidth 64 kbps. The link installation cost is linearly proportional to the distance between nodes and the number of 64 kbps channel on the link. For the 10, 20 and 30 nodes requirements tables 5, 6 and 7, respectively, show the link installation cost with single 64 kbps channel generated by DELITE.

For a given amount of unicast traffic demand, various levels of multicast traffic demands are considered. For simplicity, in this study, we use the notation M x 512 + N x 256 which denotes that, at the same time, M +N nodes of alls are generating different multicast session where M of them are 512 kbps session and the other N are 256 kbps session.

5.2 Network Design Results

Tables 8 – 22 present the installation cost for 10, 30 and 50 nodes networks obtained by M-MENTOR with ρ = 0.4, slack s = 0.2, 0 .4 and 0.6, and the total unicast traffic in/out per node of 256, 512, 1024, 2048 and 4096 kbps. Since there is no known algorithm for design of mesh IP network with mixed traffic before, for comparison, we have modified MENTOR-II to support both unicast and multicast traffic. What we have modified is that all multicast traffics are forced to flow through the backbone spanning tree of the MENTOR-II network. And thus the link capacities of the spanning tree are determined by the summation of the unicast and multicast traffic flow through them. The design results obtained by modified MENTOR-II with α = 0 (i.e. Minimum Spanning Tree: MST), 0.5 and 1 (i.e. Shortest Path Tree: SPT) are also presented in the tables in order to compare with of network obtained by M-MENTOR that have the same slack.

Table 5: 64 Kbps Channel Link Installation Cost for 10 Node Requirement

S\D	N1	N2	N3	N4	N5	N6	N7	N8	N9	N10
N1	500	1174	830	2340	2860	3504	1236	3122	1302	1718
N2	1174	500	994	1870	1182	2514	3592	3506	3348	1820
N3	830	994	500	2328	1502	2832	2006	2434	3546	2184
N4	2340	1870	2328	500	1450	2760	2912	1662	1672	2330
N5	2860	1182	1502	1450	500	2560	2690	2228	2124	1998
N6	3504	2514	2832	2760	2560	500	2716	1770	1660	1470
N7	1236	3592	2006	2912	2690	2716	500	2442	1360	1386
N8	3122	3506	2434	1662	2228	1770	2442	500	1956	1020
N9	1302	3348	3546	1672	2124	1660	1360	1956	500	1380
N10	1718	1820	2184	2330	1998	1470	1386	1020	1380	500

Table 6 : 64 Kbps Channel Link Installation Cost for 30 Node Requirement

S\D	N1	N2	N3	N4	N5	N6	N7	N8	N9	N10	N11	N12	N13	N14	N15	N16	N17	N18	N19	N20	N21	N22	N23	N24	N25	N26	N27	N28	N29	N30
N1	500	1174	994	2328	2860	3504	1236	3122	1302	1718	946	1580	1202	1720	1134	1150	830	3326	1878	3112	1822	1904	998	1148	2006	2798	2438	940	1578	1314
N2	1174	500	830	1870	1182	2514	3592	3506	3348	1820	1958	1950	1304	1976	2352	1134	1418	3000	2576	4054	2372	2066	1430	1522	2604	1294	3702	2364	2014	2370
N3	994	830	500	2348	1502	2832	2006	2434	3546	2184	2222	2324	1750	926	2574	2154	1456	2638	2274	1304	2906	1666	1940	1488	3024	818	2724	3324	2736	2808
N4	2328	1870	2348	500	1450	2760	2912	1662	1672	2330	2226	2926	2576	614	1558	2156	2368	2378	1672	1594	1020	2912	1680	2476	2274	728	2246	2492	2634	3090
N5	2860	1182	1502	1450	500	2560	2690	2228	2124	1998	2184	3166	2988	1828	1130	1392	2254	2342	1868	1968	832	1798	2698	1406	3592	1746	2422	2118	2446	2140
N6	3504	2514	2832	2760	2560	500	2716	1770	1660	1470	1870	2886	2552	1902	1824	1030	1660	3034	2700	2222	1362	1628	1438	2086	2492	2102	1942	2400	2422	2560
N7	1236	3592	2006	2912	2690	2716	500	2442	1360	1386	1874	1414	2200	2076	1522	1232	1348	2346	3208	3160	1052	1084	1194	1792	1784	1538	878	1604	2872	2780
N8	3122	3506	2434	1662	2228	1770	2442	500	1956	1020	1188	2918	1990	2220	2110	1336	912	2488	2156	2962	1854	1712	594	1464	2788	2718	3424	1120	1508	3272
N9	1302	3348	3546	1672	2124	1660	1360	1956	500	1380	1108	1200	2644	2084	2498	2618	1176	3706	1958	2462	1826	2922	1226	1074	2518	1716	4280	3276	2148	1890
N10	1718	1820	2184	2330	1998	1470	1386	1020	1380	500	1032	1678	1460	1452	2494	2842	2942	3652	2988	2122	1148	3154	2444	964	2516	1500	1458	4000	3348	2898
N11	946	1958	2222	2226	2184	1870	1874	1188	1108	1032	500	1070	1750	1452	866	1886	3170	1284	2630	1148	942	2138	2658	1974	1946	892	1784	1206	3626	3430
N12	1580	1950	2324	2926	3166	2886	1414	2918	1200	1678	1070	500	1134	1120	1966	1498	1802	662	1116	1006	1320	1714	1650	2366	1146	1502	2260	1530	1646	3328
N13	1202	1304	1750	2576	2988	2552	2200	1990	2644	1460	1750	1134	500	1408	1506	1472	1732	3662	1798	3576	1642	2156	1220	1286	1836	2702	2412	2108	1744	2250
N14	1720	1976	926	614	1828	1902	2076	2220	2084	1452	1452	1120	1408	500	2006	980	1554	2640	3450	3902	2626	1562	1840	1058	1632	2960	3212	2124	2364	2210
N15	1134	2352	2574	1558	1130	1824	1522	2110	2498	2494	866	1966	1506	2006	500	1632	1120	2992	1474	2304	2744	2242	1480	2196	2020	1926	2920	2806	1982	2698
N16	1150	1134	2154	2156	1392	1030	1232	1336	2618	2842	1886	1498	1472	980	1632	500	1788	2922	2804	2154	1634	2792	2144	2070	3068	1512	2586	2484	2014	2138
N17	830	1418	1456	2368	2254	1660	1348	912	1176	2942	3170	1802	1732	1554	1120	1788	500	2718	2472	2286	1728	3014	2558	1656	3336	2102	2304	2234	1492	1504
N18	3326	3000	2638	2378	2342	3034	2346	2488	3706	3652	1284	662	3662	2640	2992	2922	2718	500	2684	1910	1148	802	2558	1938	2180	1608	1138	2012	1804	804
N19	1878	2576	2274	1672	1868	2700	3208	2156	1958	2988	2630	1116	1798	3450	1474	2804	2472	2684	500	2558	654	2532	806	2546	1664	2080	1368	798	1892	1778
N20	3112	4054	1304	1594	1968	2222	3160	2962	2462	2122	1148	1006	3576	3902	2304	2154	2286	1910	2558	500	1306	2054	2044	1222	2624	2592	3854	1448	1514	2094
N21	1822	2372	2906	1020	832	1362	1052	1854	1826	1148	942	1320	1642	2626	2744	1634	1728	1148	654	1306	500	2588	1576	1904	2726	2872	4124	3646	2274	2252
N22	1904	2066	1666	2912	1798	1628	1084	1712	2922	3154	2138	1714	2156	1562	2242	2792	3014	802	2532	2054	2588	500	2092	1576	2040	580	2158	3840	3516	2924
N23	998	1430	1940	1680	2698	1438	1194	594	1226	2444	2658	1650	1220	1840	1480	2144	2558	2558	806	2044	1576	2092	500	1814	2210	2356	2482	1726	3464	3428
N24	1148	1522	1488	2476	1406	2086	1792	1464	1074	964	1974	2366	1286	1058	2196	2070	1656	1938	2546	1222	1904	1576	1814	500	1714	1892	2284	2392	660	3180
N25	2006	2604	3024	2274	3592	2492	1784	2788	2518	2516	1946	1146	1836	1632	2020	3068	3336	2180	1664	2624	2726	2040	2210	1714	500	2390	1994	1862	2726	1200
N26	2798	1294	818	728	1746	2102	1538	2718	1716	1500	892	1502	2702	2960	1926	1512	2102	1608	2080	2592	2872	580	2356	1892	2390	500	2588	1626	1134	3056
N27	2438	3702	2724	2246	2422	1942	878	3424	4280	1458	1784	2260	2412	3212	2920	2586	2304	1138	1368	3854	4124	2158	2482	2284	1994	2588	500	2176	1384	1244
N28	940	2364	3324	2492	2118	2400	1604	1120	3276	4000	1206	1530	2108	2124	2806	2484	2234	2012	798	1448	3646	3840	1726	2392	1862	1626	2176	500	1434	1736
N29	1578	2014	2736	2634	2446	2422	2872	1508	2148	3348	3626	1646	1744	2364	1982	2014	1492	1804	1892	1514	2274	3516	3464	660	2726	1134	1384	1434	500	1248
N30	1314	2370	2808	3090	2140	2560	2780	3272	1890	2898	3430	3328	2250	2210	2698	2138	1504	804	1778	2094	2252	2924	3428	3180	1200	3056	1244	1736	1248	500

Table 7 : 64 Kbps Channel Link Installation Cost for 50 Node Requirement

S\D	N1	N2	N3	N4	N5	N6	N7	N8	N9	N10	N11	N12	N13	N14	N15	N16	N17	N18	N19	N20	N21	N22	N23	N24	N25	N26	N27	N28	N29	N30	N31	N32	N33	N34	N35	N36	N37	N38	N39	N40	N41	N42	N43	N44	N45	N46	N47	N48	N49	N50
N1	500	1174	830	2348	1450	2560	2716	2442	1956	1380	1032	1070	1134	1408	2006	1632	1788	2718	2684	2558	1306	2588	2092	1814	1714	2390	2588	2176	1434	1248	1218	3196	1368	3070	2336	2660	1022	1704	1110	642	2128	2254	2154	862	2528	2344	2730	2182	1962	2716
N2	1174	500	994	1870	1502	2760	2690	1770	1360	1020	1108	1678	1750	1120	1506	980	1120	2922	2472	1910	654	2054	1576	1576	2210	1892	1994	1626	1384	1736	994	2708	696	2800	1746	2006	860	2274	914	1312	1610	2438	2222	1534	1880	2554	2476	1730	1462	2562
N3	830	994	500	2328	1182	2832	2912	2228	1660	1386	1188	1200	1460	1452	1966	1472	1554	2992	2804	2286	1148	2532	2044	1904	2040	2356	2284	1862	1134	1244	1268	3174	1174	3168	2236	2390	1046	1782	786	924	2078	2518	2376	1148	2370	2616	2832	2174	1642	2862
N4	2348	1870	2328	500	2860	2514	2006	1662	2124	1470	1874	2918	2644	1452	866	1498	1732	2640	1474	2154	1728	802	806	1222	2726	580	2482	2392	2726	3056	1636	1350	1762	1616	932	2160	1832	3550	2280	2480	778	2272	1922	2640	1332	2392	1388	678	2402	1656
N5	1450	1502	1182	2860	500	3504	3592	2434	1672	1998	1870	1414	1990	2084	2494	1886	1802	3662	3450	2304	1634	3014	2558	2546	2624	2872	2158	1726	660	1200	1916	3680	1600	3794	2672	2418	1702	1698	1090	1466	2590	3192	3058	1620	2688	3286	3464	2726	1486	3522
N6	2560	2760	2832	2514	3504	500	1236	3506	3546	2330	2184	2886	2200	2220	2498	2842	3170	662	1798	3902	2744	2792	2558	1938	1664	2592	4124	3840	3464	3180	2276	2954	2846	2128	2884	3954	2416	3372	3034	2578	2572	822	1114	2522	3288	718	1942	2398	3712	1628
N7	2716	2690	2912	2006	3592	1236	500	3122	3348	2184	2226	3166	2552	2076	2110	2618	2942	1284	1116	3576	2626	2242	2144	1656	2180	2080	3854	3646	3516	3428	2204	2276	2716	1396	2424	3606	2400	3734	3044	2778	2146	1232	1088	2794	2834	1274	1258	1938	3566	920
N8	2442	1770	2228	1662	2434	3506	3122	500	1302	1820	2222	2926	2988	1902	1522	1336	1176	3652	2630	1006	1642	1562	1480	2070	3336	1608	1368	1448	2274	2924	1970	2136	1576	2758	1232	1000	2018	3482	2014	2580	1476	3216	2894	2804	904	3340	2548	1688	1584	2806
N9	1956	1360	1660	2124	1672	3546	3348	1302	500	1718	1958	2324	2576	1828	1824	1232	912	3706	2988	1148	1320	2156	1840	2196	3068	2102	1138	798	1514	2252	1786	2808	1216	3222	1780	1260	1710	2804	1388	2074	1858	3228	2966	2304	1638	3350	2944	2062	796	3126
N10	1380	1020	1386	1470	1998	2330	2184	1820	1718	500	946	1950	1750	614	1130	1030	1348	2488	1958	2122	942	1714	1220	1058	2020	1512	2304	2012	1892	2094	680	2318	1036	2296	1496	2192	864	2582	1414	1512	1254	2014	1754	1684	1772	2134	1966	1304	1898	2044
N11	1032	1108	1188	1874	1870	2184	2226	2222	1958	946	500	1580	1304	926	1558	1392	1660	2346	2156	2462	1148	2138	1650	1286	1632	1926	2586	2234	1804	1778	768	2710	1248	2540	1940	2546	750	2212	1352	1138	1684	1864	1694	1270	2210	1970	2200	1700	2068	2192
N12	1070	1678	1200	2918	1414	2886	3166	2926	2324	1950	1580	500	1202	1976	2574	2156	2254	3034	3208	2962	1826	3154	2658	2366	1836	2960	2920	2484	1492	804	1786	3766	1868	3606	2892	3072	1590	1136	1440	944	2694	2602	2582	874	3058	2676	3266	2752	2246	3218
N13	1134	1750	1460	2644	1990	2200	2552	2988	2576	1750	1304	1202	500	1720	2352	2154	2368	2342	2700	3160	1854	2922	2444	1974	1146	2702	3212	2806	2014	1504	1570	3454	1936	3114	2742	3254	1472	1690	1744	1048	2478	1936	1964	874	3008	1994	2782	2468	2594	2672
N14	1408	1120	1452	1452	2084	2220	2076	1902	1828	614	926	1976	1720	500	1134	1134	1456	2378	1868	2222	1052	1712	1226	964	1946	1502	2412	2124	1982	2138	692	2294	1146	2218	1528	2290	910	2610	1504	1534	1262	1904	1642	1690	1828	2026	1886	1280	2010	1948
N15	2006	1506	1966	866	2494	2498	2110	1522	1824	1130	1558	2574	2352	1134	500	1150	1418	2638	1672	1968	1362	1084	594	1074	2516	892	2260	2108	2364	2698	1304	1710	1398	1902	926	1998	1486	3202	1914	2140	628	2220	1886	2312	1302	2344	1622	746	2090	1826
N16	1632	980	1472	1498	1886	2842	2618	1336	1232	1030	1392	2156	2154	1134	1150	500	830	3000	2274	1594	832	1628	1194	1464	2518	1500	1784	1530	1744	2210	1154	2296	804	2542	1290	1666	1184	2754	1336	1774	1222	2530	2250	1988	1402	2654	2246	1394	1464	2404
N17	1788	1120	1554	1732	1802	3170	2942	1176	912	1348	1660	2254	2368	1456	1418	830	500	3326	2576	1304	1020	1798	1438	1792	2788	1716	1458	1206	1646	2250	1448	2462	932	2818	1426	1392	1424	2806	1340	1922	1460	2856	2580	2150	1388	2978	2536	1658	1174	2714
N18	2718	2922	2992	2640	3662	662	1284	3652	3706	2488	2346	3034	2342	2378	2638	3000	3326	500	1878	4054	2906	2912	2698	2086	1784	2718	4280	4000	3626	3328	2436	3040	3008	2180	3018	4104	2578	3506	3194	2734	2710	984	1260	2670	3424	878	2022	2530	3872	1694
N19	2684	2472	2804	1474	3450	1798	1116	2630	2988	1958	2156	3208	2700	1868	1672	2274	2576	1878	500	3112	2372	1666	1680	1406	2492	1538	3424	3276	3348	3430	2040	1666	2446	918	1906	3128	2260	3822	2870	2778	1672	1680	1380	2856	2302	1766	646	1454	3238	702
N20	2558	1910	2286	2154	2304	3902	3576	1006	1148	2122	2462	2962	3160	2222	1968	1594	1304	4054	3112	500	1822	2066	1940	2476	3592	2102	878	1120	2148	2898	2242	2630	1730	3258	1730	616	2228	3450	2024	2686	1944	3600	3296	2916	1402	3724	3038	2162	1334	3282
N21	1306	654	1148	1728	1634	2744	2626	1642	1320	942	1148	1826	1854	1052	1362	832	1020	2906	2372	1822	500	1904	1430	1488	2274	1746	1942	1604	1508	1890	972	2560	604	2686	1592	1912	906	2428	1052	1446	1462	2424	2184	1664	1732	2542	2366	1594	1468	2472
N22	2588	2054	2532	802	3014	2792	2242	1562	2156	1714	2138	3154	2922	1712	1084	1628	1798	2912	1666	2066	1904	500	998	1522	3024	728	2422	2400	2872	3272	1888	1170	1918	1714	876	2054	2068	3782	2450	2722	962	2560	2208	2896	1178	2678	1556	970	2448	1862
N23	2092	1576	2044	806	2558	2558	2144	1480	1840	1220	1650	2658	2444	1226	594	1194	1438	2698	1680	1940	1430	998	500	1148	2604	818	2246	2118	2422	2780	1394	1634	1458	1884	842	1964	1572	3288	1982	2226	536	2286	1948	2402	1232	2410	1618	728	2112	1844
N24	1814	1576	1904	1222	2546	1938	1656	2070	2196	1058	1286	2366	1974	964	1074	1464	1792	2086	1406	2476	1488	1522	1148	500	2006	1294	2724	2492	2446	2560	1138	1986	1574	1766	1488	2522	1360	2996	1966	1924	1170	1650	1326	2040	1874	1776	1428	1056	2412	1488
N25	1714	2210	2040	2726	2624	1664	2180	3336	3068	2020	1632	1836	1146	1946	2516	2518	2788	1784	2492	3592	2274	3024	2604	2006	500	2798	3702	3324	2634	2140	1868	3448	2372	2904	2938	3676	1868	2236	2308	1664	2634	1468	1636	1518	3270	1484	2606	2558	3134	2410
N26	2390	1892	2356	580	2872	2592	2080	1608	2102	1512	1926	2960	2702	1502	892	1500	1716	2718	1538	2102	1746	728	818	1294	2798	500	2438	2364	2736	3090	1682	1318	1774	1658	876	2106	1872	3590	2298	2524	784	2352	2000	2688	1266	2470	1444	742	2384	1724
N27	2588	1994	2284	2482	2158	4124	3854	1368	1138	2304	2586	2920	3212	2412	2260	1784	1458	4280	3424	878	1942	2422	2246	2724	3702	2438	500	940	2014	2808	2396	3002	1840	3596	2070	948	2340	3346	2002	2702	2254	3814	3530	2930	1770	3936	3358	2472	1184	3584
N28	2176	1626	1862	2392	1726	3840	3646	1448	798	2012	2234	2484	2806	2124	2108	1530	1206	4000	3276	1120	1604	2400	2118	2492	3324	2364	940	500	1578	2370	2074	3034	1500	3500	2026	1232	1984	2908	1578	2284	2134	3522	3264	2510	1826	3642	3230	2344	744	3418
N29	1434	1384	1134	2726	660	3464	3516	2274	1514	1892	1804	1492	2014	1982	2364	1744	1646	3626	3348	2148	1508	2872	2422	2446	2634	2736	2014	1578	500	1314	1824	3538	1466	3682	2524	2262	1616	1834	980	1472	2454	3148	2996	1650	2532	3248	3356	2598	1336	3428
N30	1248	1736	1244	3056	1200	3180	3428	2924	2252	2094	1778	804	1504	2138	2698	2210	2250	3328	3430	2898	1890	3272	2780	2560	2140	3090	2808	2370	1314	500	1948	3906	1910	3816	2980	3010	1734	1058	1412	1156	2814	2894	2850	1158	3100	2966	3476	2896	2126	3454
N31	1218	994	1268	1636	1916	2276	2204	1970	1786	680	768	1786	1570	692	1304	1154	1448	2436	2040	2242	972	1888	1394	1138	1868	1682	2396	2074	1824	1948	500	2482	1076	2400	1676	2318	724	2420	1346	1346	1430	1956	1728	1510	1944	2072	2064	1466	1936	2108
N32	3196	2708	3174	1350	3680	2954	2276	2136	2808	2318	2710	3766	3454	2294	1710	2296	2462	3040	1666	2630	2560	1170	1634	1986	3448	1318	3002	3034	3538	3906	2482	500	2582	1474	1536	2592	2680	4400	3110	3326	1600	2796	2456	3480	1734	2896	1522	1516	3102	1858
N33	1368	696	1174	1762	1600	2846	2716	1576	1216	1036	1248	1868	1936	1146	1398	804	932	3008	2446	1730	604	1918	1458	1574	2372	1774	1840	1500	1466	1910	1076	2582	500	2748	1590	1822	1004	2454	1036	1506	1490	2528	2284	1730	1696	2646	2436	1636	1368	2552
N34	3070	2800	3168	1616	3794	2128	1396	2758	3222	2296	2540	3606	3114	2218	1902	2542	2818	2180	918	3258	2686	1714	1884	1766	2904	1658	3596	3500	3682	3816	2400	1474	2748	500	2030	3254	2622	4224	3208	3170	1866	2058	1780	3258	2390	2130	842	1660	3490	1016
N35	2336	1746	2236	932	2672	2884	2424	1232	1780	1496	1940	2892	2742	1528	926	1290	1426	3018	1906	1730	1592	876	842	1488	2938	876	2070	2026	2524	2980	1676	1536	1590	2030	500	1732	1824	3508	2124	2474	820	2618	2276	2666	910	2742	1818	992	2072	2086
N36	2660	2006	2390	2160	2418	3954	3606	1000	1260	2192	2546	3072	3254	2290	1998	1666	1392	4104	3128	616	1912	2054	1964	2522	3676	2106	948	1232	2262	3010	2318	2592	1822	3254	1732	500	2316	3564	2132	2788	1966	3654	3346	3018	1380	3780	3046	2180	1450	3300
N37	1022	860	1046	1832	1702	2416	2400	2018	1710	864	750	1590	1472	910	1486	1184	1424	2578	2260	2228	906	2068	1572	1360	1868	1872	2340	1984	1616	1734	724	2680	1004	2622	1824	2316	500	2220	1146	1156	1608	2094	1898	1344	2048	2206	2286	1668	1820	2322
N38	1704	2274	1782	3550	1698	3372	3734	3482	2804	2582	2212	1136	1690	2610	3202	2754	2806	3506	3822	3450	2428	3782	3288	2996	2236	3590	3346	2908	1834	1058	2420	4400	2454	4224	3508	3564	2220	500	1970	1578	3322	3122	3146	1468	3648	3172	3886	3384	2664	3820
N39	1110	914	786	2280	1090	3034	3044	2014	1388	1414	1352	1440	1744	1504	1914	1336	1340	3194	2870	2024	1052	2450	1982	1966	2308	2298	2002	1578	980	1412	1346	3110	1036	3208	2124	2132	1146	1970	500	1208	2014	2714	2538	1432	2200	2818	2880	2142	1356	2948
N40	642	1312	924	2480	1466	2578	2778	2580	2074	1512	1138	944	1048	1534	2140	1774	1922	2734	2778	2686	1446	2722	2226	1924	1664	2524	2702	2284	1472	1156	1346	3326	1506	3170	2474	2788	1156	1578	1208	500	2262	2278	2206	730	2670	2362	2830	2312	2064	2800
N41	2128	1610	2078	778	2590	2572	2146	1476	1858	1254	1684	2694	2478	1262	628	1222	1460	2710	1672	1944	1462	962	536	1170	2634	784	2254	2134	2454	2814	1430	1600	1490	1866	820	1966	1608	3322	2014	2262	500	2304	1962	2438	1216	2426	1608	718	2132	1838
N42	2254	2438	2518	2272	3192	822	1232	3216	3228	2014	1864	2608	1936	1904	2220	2530	2856	984	1680	3600	2424	2560	2286	1650	1468	2352	3814	3522	3148	2894	1956	2796	2528	2058	2618	3654	2094	3122	2714	2278	2304	500	854	2238	3016	626	1818	2142	3390	1544
N43	2154	2222	2376	1922	3058	1114	1088	2894	2966	1754	1694	2582	1964	1642	1886	2250	2580	1260	1380	3296	2184	2208	1948	1326	1636	2000	3530	3264	2996	2850	1728	2456	2284	1780	2276	3346	1898	3146	2538	2206	1962	854	500	2210	2678	970	1506	1794	3150	1276
N44	862	1534	1148	2640	1620	2522	2794	2804	2304	1684	1270	874	874	1690	2312	1988	2150	2670	2856	2916	1664	2896	2402	2040	1518	2688	2930	2510	1650	1158	1510	3480	1730	3258	2666	3018	1344	1468	1432	730	2438	2238	2210	500	2880	2308	2920	2468	2286	2858
N45	2528	1880	2370	1332	2688	3288	2834	904	1638	1772	2210	3058	3008	1828	1302	1402	1388	3424	2302	1402	1732	1178	1232	1874	3270	1266	1770	1826	2532	3100	1944	1734	1696	2390	910	1380	2048	3648	2200	2670	1216	3016	2678	2880	500	3140	2206	1402	1930	2488
N46	2344	2554	2616	2392	3286	718	1274	3340	3350	2134	1970	2676	1994	2026	2344	2654	2978	878	1766	3724	2542	2678	2410	1776	1484	2470	3936	3642	3248	2966	2072	2896	2646	2130	2742	3780	2206	3172	2818	2362	2426	626	970	2308	3140	500	1904	2262	3508	1616
N47	2730	2476	2832	1388	3464	1942	1258	2548	2944	1966	2200	3266	2782	1886	1622	2246	2536	2022	646	3038	2366	1556	1618	1428	2606	1444	3358	3230	3356	3476	2064	1522	2436	842	1818	3046	2286	3886	2880	2830	1608	1818	1506	2920	2206	1904	500	1392	3204	840
N48	2182	1730	2174	678	2726	2398	1938	1688	2062	1304	1700	2752	2468	1280	746	1394	1658	2530	1454	2162	1594	970	728	1056	2558	742	2472	2344	2598	2896	1466	1516	1636	1660	992	2180	1668	3384	2142	2312	718	2142	1794	2468	1402	2262	1392	500	2332	1622
N49	1962	1462	1642	2402	1486	3712	3566	1584	796	1898	2068	2246	2594	2010	2090	1464	1174	3872	3238	1334	1468	2448	2112	2412	3134	2384	1184	744	1336	2126	1936	3102	1368	3490	2072	1450	1820	2664	1356	2064	2132	3390	3150	2286	1930	3508	3204	2332	500	3366
N50	2716	2562	2862	1656	3522	1628	920	2806	3126	2044	2192	3218	2672	1948	1826	2404	2714	1694	702	3282	2472	1862	1844	1488	2410	1724	3584	3418	3428	3454	2108	1858	2552	1016	2086	3300	2322	3820	2948	2800	1838	1544	1276	2858	2488	1616	840	1622	3366	500

Table 8: Installation cost of 10 node network with total unicast traffic in/out of 256 Kbps

Multicast Traffic	slack	M-MENTOR	MENTOR-II		
			α =0	α = 0.5	α = 1
2x512+ 6x256	0.2	10430	11400	13616	15140
	0.4	11684	12160	14226	15772
	0.6	12248	12864	15905	16834
4x512+ 4x25	0.2	12862	13374	15457	16957
	0.4	14438	15976	16885	17206
	0.6	16825	18157	19215	19848
6x512+ 2x256	0.2	14045	14365	16125	17426
	0.4	16526	18853	19596	19632
	0.6	19986	20268	20904	21159

Table 9: Installation cost of 10 node network with total unicast traffic in/out of 512 Kbps

Multicast Traffic	slack	M-MENTOR	MENTOR-II		
			α =0	α = 0.5	α = 1
2x512+ 6x256	0.2	12216	12537	13892	15524
	0.4	14560	14763	16162	17873
	0.6	15656	16930	17483	19201
4x512+ 4x25	0.2	13463	13834	15314	17027
	0.4	16862	17164	18855	19480
	0.6	17289	18583	19238	20772
6x512+ 2x256	0.2	15320	15376	16993	17738
	0.4	16756	17860	18423	19912
	0.6	20952	21027	21829	22114

Table 10: Installation cost of 10 node network with total unicast traffic in/out of 1024 Kbps

Multicast Traffic	slack	M-MENTOR	MENTOR-II		
			α =0	α = 0.5	α = 1
2x512+ 6x256	0.2	14728	14920	16378	17902
	0.4	16803	17209	18839	19328
	0.6	17264	18678	19238	20728
4x512+ 4x25	0.2	16172	17427	18537	19392
	0.4	17489	18874	19839	20795
	0.6	18638	18928	19299	20945
6x512+ 2x256	0.2	16284	17538	18783	19458
	0.4	17620	18947	19944	20722
	0.6	20114	21264	21326	22928

Table 11: Installation cost of 10 node network with total unicast traffic in/out of 2048 Kbps

Multicast Traffic	slack	M-MENTOR	MENTOR-II		
			α =0	α = 0.5	α = 1
2x512+ 6x256	0.2	16138	16483	17672	18628
	0.4	17433	18820	19930	20920
	0.6	19894	20281	21218	22219
4x512+ 4x25	0.2	17829	18978	19839	20829
	0.4	18945	19281	20281	21114
	0.6	20575	20839	22839	23438
6x512+ 2x256	0.2	19118	19271	20921	21930
	0.4	20439	20629	21218	22103
	0.6	21842	21920	22618	23543

Table 12: Installation cost of 10 node network with total unicast traffic in/out of 4096 Kbps

Multicast Traffic	slack	M-MENTOR	MENTOR-II		
			α =0	α = 0.5	α = 1
2x512+ 6x256	0.2	20748	19849	22955	24184
	0.4	20022	20294	23329	24499
	0.6	21493	21543	22849	25893
4x512+ 4x25	0.2	22431	23452	25198	25384
	0.4	23738	24873	26493	29594
	0.6	27839	29918	29899	30883
6x512+ 2x256	0.2	23855	24890	25783	26739
	0.4	25937	26182	28990	30922
	0.6	29211	31483	32352	33274

Table 13: Installation cost of 30 node network with total unicast traffic in/out of 256 Kbps

Multicast Traffic	slack	M-MENTOR	MENTOR-II		
			α =0	α = 0.5	α = 1
6x512+ 18x256	0.2	34586	36270	44250	47410
	0.4	35632	36459	44567	47974
	0.6	38473	38943	45362	48348
12x512+ 12x25	0.2	36958	37845	45365	48594
	0.4	38647	40432	47948	49320
	0.6	40865	43854	51844	52043
18x512+ 6x256	0.2	40538	40538	48357	50384
	0.4	41847	42843	51335	52367
	0.6	43562	46484	52847	53475

Table 14: Installation cost of 30 node network with total unicast traffic in/out of 512 Kbps

Multicast Traffic	slack	M-MENTOR	MENTOR-II		
			α =0	α = 0.5	α = 1
6x512+ 18x256	0.2	40372	41746	45374	48438
	0.4	42847	43728	47384	50324
	0.6	47487	48739	50387	51472
12x512+ 12x25	0.2	46378	48376	49578	51362
	0.4	49384	50367	52748	53892
	0.6	52832	54633	54218	54362
18x512+ 6x256	0.2	52738	52738	53127	53728
	0.4	53627	53627	54372	55382
	0.6	53903	54637	55283	56372

Table 15: Installation cost of 30 node network with total unicast traffic in/out of 1024 Kbps

Multicast Traffic	slack	M-MENTOR	MENTOR-II		
			α =0	α = 0.5	α = 1
6x512+ 18x256	0.2	48374	49302	49302	51894
	0.4	49374	49374	50758	54378
	0.6	50489	51394	52948	55938
12x512+ 12x25	0.2	49803	50549	51948	55281
	0.4	51038	52849	53849	58394
	0.6	55847	57384	59847	61346
18x512+ 6x256	0.2	52748	53472	54637	60483
	0.4	55493	55493	57439	62849
	0.6	49083	61849	63584	64839

Table 16: Installation cost of 30 node network with total unicast traffic in/out of 2048 Kbps

Multicast Traffic	slack	M-MENTOR	MENTOR-II		
			α = 0	α = 0.5	α = 1
6x512+ 18x256	0.2	50473	50473	51847	55374
	0.4	50973	51849	53948	57483
	0.6	51756	52673	54890	58494
12x512+ 12x25	0.2	50438	51874	59039	57849
	0.4	53746	55849	60487	60382
	0.6	57684	58393	62847	63928
18x512+ 6x256	0.2	57467	58948	59860	60485
	0.4	59485	60494	62748	63859
	0.6	61857	62847	65489	66854

Table 17: Installation cost of 30 node network with total unicast traffic in/out of 4096 Kbps

Multicast Traffic	slack	M-MENTOR	MENTOR-II		
			α = 0	α = 0.5	α = 1
6x512+ 18x256	0.2	53467	53467	58475	60284
	0.4	55768	56372	59485	62837
	0.6	60574	61738	63849	64738
12x512+ 12x25	0.2	62547	62547	62547	63748
	0.4	62768	63546	64758	66478
	0.6	63758	64564	67483	68476
18x512+ 6x256	0.2	62786	63758	65374	67463
	0.4	64768	65867	67645	69478
	0.6	66970	67869	69384	71647

Table 18: Installation cost of 50 node network with total unicast traffic in/out of 256 Kbps

Multicast Traffic	slack	M-MENTOR	MENTOR-II		
			α = 0	α = 0.5	α = 1
10x512+ 30x256	0.2	38134	39690	43890	59650
	0.4	38845	40495	44192	60581
	0.6	39520	41345	45648	61378
20x512+ 20x25	0.2	39148	40982	44357	60964
	0.4	39850	41385	45856	61851
	0.6	41183	42724	46364	62774
30x512+ 10x256	0.2	40643	41638	46032	62157
	0.4	41749	42581	46790	62814
	0.6	42752	43485	47371	63825

Table 19: Installation cost of 50 node network with total unicast traffic in/out of 512 Kbps

Multicast Traffic	slack	M-MENTOR	MENTOR-II		
			α = 0	α = 0.5	α = 1
10x512+ 30x256	0.2	39231	40712	44061	60824
	0.4	40574	41664	44945	61367
	0.6	41259	42305	46123	62231
20x512+ 20x25	0.2	40532	41563	44926	61247
	0.4	41576	41903	45945	62394
	0.6	42183	42945	47190	63283
30x512+ 10x256	0.2	42227	42594	46583	62954
	0.4	42879	43186	47243	63436
	0.6	43472	43975	48521	64221

Table 20: Installation cost of 50 node network with total unicast traffic in/out of 1024 Kbps

Multicast Traffic	slack	M-MENTOR	MENTOR-II		
			α = 0	α = 0.5	α = 1
10x512+ 30x256	0.2	40365	41475	44724	61428
	0.4	41634	42193	45638	62248
	0.6	42254	42978	46883	63482
20x512+ 20x25	0.2	41749	42532	45931	62185
	0.4	42364	42954	46365	63854
	0.6	42698	43367	47811	64284
30x512+ 10x256	0.2	42786	43276	47365	63265
	0.4	43458	44675	47956	64462
	0.6	44284	45834	49257	65398

Table 21: Installation cost of 50 node network with total unicast traffic in/out of 2048 Kbps

Multicast Traffic	slack	M-MENTOR	MENTOR-II		
			α = 0	α = 0.5	α = 1
10x512+ 30x256	0.2	41685	42256	42256	62456
	0.4	42490	43678	43898	63648
	0.6	43643	44394	45274	64267
20x512+ 20x25	0.2	43574	43854	46426	63389
	0.4	43685	44253	46852	64286
	0.6	43894	44845	48258	65378
30x512+ 10x256	0.2	43584	43857	47899	63992
	0.4	44367	45684	48538	65170
	0.6	45336	46936	49703	66357

Table 22: Installation cost of 30 node network with total unicast traffic in/out of 4096 Kbps

Multicast Traffic	slack	M-MENTOR	MENTOR-II		
			α = 0	α = 0.5	α = 1
10x512+ 30x256	0.2	43056	43224	42804	63109
	0.4	43857	44217	44730	64743
	0.6	44721	45134	45997	65807
20x512+ 20x25	0.2	44652	44906	47255	64423
	0.4	44978	45354	47658	65284
	0.6	45143	45852	48957	65920
30x512+ 10x256	0.2	44365	44707	48865	64889
	0.4	44795	45290	49573	65902
	0.6	45644	46456	50965	67348

It can be observed from tables 8 – 22 that:

1) Given a value of slack, almost all cases M-MENTOR gives the minimum installation cost. On the other hand, MENTOR-II, the installation cost increase as α increase.
2) Given a traffic demand, the installation cost tends to increase as slack increase.
3) As traffic demands increase, either unicast or multicast, the installation cost increase.

6 Conclusion

This study proposes an IP network design algorithm called M-MENTOR that support both unicast and multicast traffic simultanously. However, since multicast traffic model could be employed in many situations and could be managed by various kinds of multicast routing protocols, this paper consider only the IP networks with following features: (1) network of within the same Autonomous System (AS), (2) routing protocol support multiple weight on each link, (3) the multicast traffic from different sources share the same multicast tree. M-MENTOR is a modified version of MENTOR-II that uses Modified T-M algorithm, rather than Prim-Dijkstra Algorithm, to construct backbone spanning tree. An example of 6 backbone nodes network design is given.

The efficiency of M-MENTOR is evaluated in term of network installation cost. The installation cost of 10, 30 and 50 backbone nodes networks designed by M-MENTOR are calculated and compared with that of MENTOR-II with various design parameters and various conditions of mixed traffics. It is shown that, all most all cases, M-MENTOR networks give lowest installation cost. For the case of MENTOR-II, networks with lower α tend to give better performance.

References:

[1] Pisit Charnkeitkong, *Computer Network Design – Requirement Analysis, Architecture and Topology Design*, 1st Edition, Rangsit University Press, October 2007 [in Thai],

[2] Aaron Kershenbaum, Parviz Kermani, and George A. Grover, MENTOR: *An Algorithm for Mesh Network Topological Optimization and Routing*, *IEEE Transaction on Communications,* Vol.39, April 1991, pp.503-513.

[3] Kairat Jaroenrat and Pisit Charnkeitkong, *On Routing Performance of MENTOR Algorithm*, WSEAS TRANSACTION ON COMMUNICA-TIONS, Issue 9, Vol.5, September 2006, pp. 1769-1776.

[4] Pisit Charnkeitkong, Kairat Jaroenrat and Pakdee Keatthalerenglit, *On IP Network Routing Per-formance of MENTOR-II Algorithm*, Proceedings of IT Towards Empowerment International Conference, November 26-26, 2007, Bangkok, Thailand.

[5] Robert Cahn, *Wide Area Network Design*, Morgan Kaufmann Publisher, San Francisco, CA, 1998

[6] H. Takahashi and A. Matsuyama, *An approximate solution for the Steiner problem in graphs*, Math. Japonica, vol. 6, pp. 533–577

[7] Ning Wang and George Pavlou, Traffic Engineered Multicast Content Delivery Without MPLS Overlay, *IEEE TRANSACTIONS ON MULTIMEDIA,* VOL. 9, NO. 3, APRIL 2007, pp.619-628.

[8] T. Przygienda, N. Shen, and N. Sheth, *M-ISIS: Multi Topology (MT) Routing in IS-IS 2005* [Online]. Available: draft-ietf-isis-wg-multitopology-11.txt

[9] Bernard Fortz and Mikkel Thorup, *Internet traffic engineering by optimizing OSPF weights*, *Proc. IEEE INFOCOM,* vol. 2, Mar. 2000, pp.519–528.

[10] Nicholas F. Maxemchuk, *Video Distribution on Multicast Networks*, *IEEE JOURNAL ON SELECTED AREAS IN COMMUNICATIONS,* VOL. 15, NO. 3, APRIL 1997, pp.357-372.