SRAD: Smart Routing Algorithm Design for Supporting IoT Network Architecture

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Abstract: The smart things require applications and services such as high-speed wireless, high-definition IP video cameras, and high-bandwidth connectivity. Therefore, Fog computing is responsible reducing the amount of data sent to the cloud with smart router over the core network. The IP/MPLS network design to support unicast traffic under delay constraints is a severe problem. To realize such design, especially for communication networks that can be represented by M/M/1 model, this paper develops an algorithm based on Mesh Network Topological Optimization and Routing (MENTOR)-II was called “Smart MENTOR-II”. The simulation results show that, in almost all test cases, the proposed algorithm yields lower installation cost and delay constraints than the ordinary MENTOR-II.

Keywords: Smart Things, Fog Computing, Cloud Computing, IP/MPLS Network Design, MENTOR-II Algorithm, M/M/1 Model, Unicast Traffic**.**

1. Introduction

Nowadays, Internet of Things (IoT) has been enjoying a very rapid growth. In 2020, the evolution of so-called smart things around 50 billion connected devices, which include machines, wearables, sensors and embedded systems. The device connected to WiFi, Bluetooth, ZigBee, UWB, 4G/LTE, NFC, LoRa, Sigfox, and WiMax. The IoT systems use of Internet protocols to run over IP rather than proprietary transports. Also greater adoption and support for IPv4/IPv6 in carrier networks. The smart devices are a part of the broader concept such as agriculture, smart city, industrial automation, smart home, smart grid, healthcare, intelligent buildings, intelligent transportation, and defense. The device is using all IP address based, IP/MPLS [1] is used for the backhaul and core transport networks that connect various end-points. Also, although the current approach toward IoT is being based on centralized management of IoT using cluster of cloud-based servers, it is being recognized that with the fast increase in the number of objects connected to the IoT, the centralized cloud-based management [15].

Fog computing [2] adds a hierarchy approach to computing, storage, control and networking anywhere along the continuum from the cloud to smart things [16], to meet these challenges in high performance and interoperable way. Therefore, a routing algorithm finds the best path on IP/MPLS core network is designed to give effect to service delivery, and service support is significant.

Internet Protocol (IP) network design which concerns unicast routing [3] remains a severe problem. The problem is even more challenging if we choose to manage the traffic by the appropriate setting of link weights in the Open Shortest Path First (OSPF) protocol instead of using the overlay network technique. This kind of problem can be classified as Mixed Integer Linear Programming (MIP) [4].

To reduce the complexity of the network design process, Kershenbaum et al. [5] developed a heuristic algorithm, called MENTOR (Mesh Network Topological Optimization and Routing). The networks designed by this algorithm may be able to give near-optimal routing performance [6]. MENTOR can also be used to design virtual circuit switching and packet switching networks such as Asynchronous Transfer Mode (ATM) and frame relay. However, it cannot be directly used to design routers or Multiprotocol Label Switching (MPLS) networks [7] that employ OSPF or Intermediate-System-to-Intermediate-System (ISIS) routing protocol. This is because MENTOR does not perform an appropriate link weight setting. Cahn [8] improved the MENTOR algorithm such that appropriate OSPF link weights can be set during the design process using Incremental Shortest Path (ISP). This improved version is known as MENTOR-II. We use to design for minimum distance networks has increased complexity. However, it should be noted that almost all the above design algorithms were being developed for networks with only unicast traffic. To efficiently design communication networks with delay constraints, especially the networks that can be represented by M/M/1 model [9], this paper develops an algorithm based on MENTOR-II. Instead of fixing all design parameters as in the ordinary MENTOR-II, this algorithm determines the maximum utilization of a link based on its delay and capacity. It allows us to control directly of the network delay. Here, the performances of networks designed by the proposed algorithm are evaluated regarding installation cost and compared with those of networks designed by the ordinary MENTOR-II for various traffic demands and different numbers of nodes.

The rest of the paper is organized as follows. In Section II, the MENTOR and MENTOR-II algorithms are introduced. In Section III, we explain how the maximum link utilization is determined by the link delay and capacity. In Section IV, an example of 10-node network design is given. In Section V, given a maximum network delay of 5 ms and maximum link delays of 1.712 ms, 3 ms, and 5 ms for 10-node networks, respectively, the cost of networks designed by the proposed algorithm is evaluated and compared with that of networks designed by the MENTOR-II algorithm.

2. Background

2.1 IoT Network Architecture Layers

The IoT infrastructure architecture [10] is composed of 4 layers as shown in Figure 1.

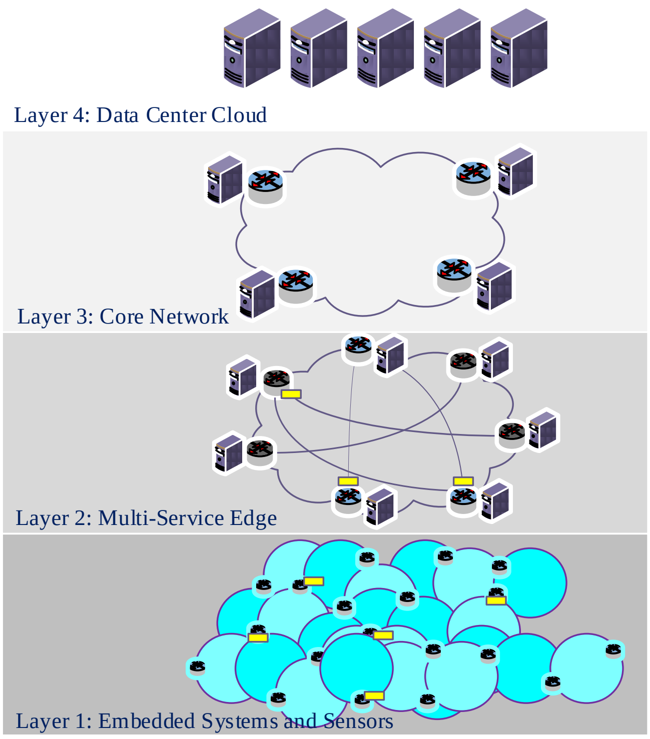

Figure 1. The 4 Layers of IoT Network Architecture

1) Embedded Systems and Sensors Layers: the first layer of the IoT architecture is comprised of embedded systems and sensors [17]. As such, these are smart, less smart things, vehicles, and machines. The device connected to wired or wireless technology. Also, although the current approach toward smart things is based on rich (mobile) clients, edge stack, routing, QoS, and CAC.

2) Multi-Service Edge: The variance of smart devices and their potentially enormous numbers highlight the importance of the multi-service edge in the IoT architecture. This layer must support many different protocols, such as Bluetooth, Zigbee, WiFi, 3G, 4G, Ethernet, and PLC to accommodate a variety of smart device. Therefore, the only way to communicate between Edge Router, Access Point, Fog Computing, Storage, Data Management, Control Logic, and Industrial Ethernet.

3) Core Network Layer: The architecture of the core network layer is IP/MPLS architecture. The function of this layer is to provide paths to carry and exchange data and network information between multiple sub-networks as require Low Jitter, Precise Scheduling, Loss-less Convergence, Multi-path switching. In this layer responsible, there are QoS, Multicast, Security, Network Service and Mobile Packet Core. Such as Mobility and Infrastructure Routing, Distributed Data Center, and Fog Service Delivery Support.

4) Data Center Cloud Layer: The architecture of the data center cloud layer is that ensure efficiency agility and openness for your users, applications, and data. Again, cloud services in this layer are Data Center Computer, Storage, Networking, Cloud Computing, Service/Apps Delivery Support, and Cisco's Apps.

2.2 MENTOR Algorithm

MENTOR is our archetype for a high-quality, low-complexity of core network design s a heuristic algorithm. The total complexity of an intelligent algorithm is only $O(n^2)$. The properties of networks designed by this algorithm are: 1) traffic is 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, network nodes are classified into end nodes and core nodes using a clustering algorithm. Examples of possible clustering algorithms are threshold clustering and *K*-mean clustering. Here, we consider only the case where traffic demands are distributed equivalently among all nodes. All the nodes can be considered as core nodes.

Next, a suitable tree is formed to interconnect all (core) nodes. Kershenbaum *et al.* [11] suggested a heuristic algorithm, which can be thought of as a modification of Prim's algorithm and Dijkstra's algorithm to build the tree. This algorithm works similarly to Dijkstra's algorithm but with a tunable parameter α ($0 \leq \alpha \leq 1$). Note that $\alpha = 0$ and 1 correspond to Minimum Spanning Tree (MST) and Shortest Path Tree (SPT), respectively.

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

2.3 MENTOR-II Algorithm

It has to do considerably more work at the direct-link addition stage. Similar to the previous algorithm, MENTOR-II [12] starts with clustering network nodes and building a good spanning tree between core nodes. However, when considering adding a direct link to serve the traffic demand between a pair of nodes, MENTOR-II calculates an appropriate weight for this link by using Incremental Shortest Path (ISP) algorithm. The concept of MENTOR-II can be described as follows:

1) Set the weight for each link in the selected good spanning tree proportional to the installation cost of the link;

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

3) When considering whether to add a link L_{AB} between A and B, the weight w_{AB} of the 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 w_{AB}. The constraint is that w_{AB} should be greater or equal to the installation cost;

4) *The* L_{AB} is added if an eligible value of w_{AB} can be found and the amount of traffic flow though it falls in the reasonable zone defined by ρ, C_{AB}, and s.

When all possible direct links are considered, they are assigned with appropriate weights which ensure the shortest path routing.

3. Design parameters

The MENTOR family allows us to construct good mesh networks efficiently. However, it does not give any idea of how to choose the design parameters, e.g., α, ρ, and s, to achieve the designed constraints. Hence, one may have to perform an exhaustive search of all possible combination of such parameters to find the optimum solution.

In this paper, focus on the problem of minimizing the installation cost with delay constraints such as the maximum link delay and maximum end-to-end delay, especially for networks that can be represented by M/M/1 model [13]. For this model, the average link delay is given by

$$T = T_p + T_q \tag{1}$$

T_p is the propagation delay which depends on the link distance, and T_q is the average queuing delay:

$$T_q = \frac{P_s}{(1-U)C} \tag{2}$$

P_s is the average packet size in a bit, U is the link utilization, and C is the link capacity, i.e., for a network designed by MENTOR,

$$T_q \le \frac{P_s}{(1-\rho)C}. \tag{3}$$

It should be noted that, for the ordinary MENTOR, the design parameters such as ρ and P_s are kept constant for all links. As a consequence, a link with small capacity always suffers more delay than the one with large capacity. To avoid the significant delay of the former link, one should try to keep ρ as small as possible. An algorithm may lead to inefficient utilization of a large-capacity link, which is more expensive. Therefore, from (1) and (3), instead of using the same value of ρ for all links, let ρ be determined by

$$\rho < \Lambda := 1 - \frac{P_s}{T\,C} \tag{4}$$

T It is the maximum allowable link delay of the overall network. Based on (4), a link with a large capacity is allowed to have more efficient utilization for given average packet size and maximum allowable link delay, e.g., see Table I.

Another advantage of using the variable maximum link utilization of (4) is that the MENTOR search domain can be reduced. Let $C_x = x \cdot C_1$ where C_1 is the capacity of a single-channel link, e.g., 10 Mbps in Table 1. From (4), the upper limit Λ_x of ρ_x for a link of capacity C_x

Table 1. Upper limit of link utilization based on capacity (P_s = 10,240 bits, T = 1.715)

Number of 10-Mbps Channels (*x*)	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
Λ_x	0.30	0.65	0.77	0.825	0.86	0.88	0.9	0.912	0.92	0.93

$$\Lambda_x = 1 - \frac{1-\Lambda_1}{x}. \tag{5}$$

In another word, changing the value of Λ_1 changes all the values of other Λ_x. As a result, in the search process, only Λ_1 is subjected to be varied to find the optimum solution. In comparison with the ordinary MENTOR-II, the optimum search domain of the maximum link utilization is reduced from all possible ρ in $(0,1)$ to $(0,\Lambda_1)$.

4. Experimental Setup

4.1 Requirements

Let us assume that an organization designs a network composed of 10 core nodes as shown in Figure 2, where the distance between any pair of them is within 100 km. Moreover, this network must support unicast traffic. Table 2 shows the unicast traffic demands between core nodes in the network.

Assume further that one or more 10-Mbps channels can be installed in a link. Table 3 shows the installation cost of 10-Mbps channel links between all possible node pairs. Let P_s be 12,288 bits. The goal of the network design is to find the network with minimum installation cost, given that the maximum end-to-end delay and maximum link delay are 5 ms and 1.715 ms, respectively.

Table 2. Unicast traffic demands between backbone nodes

S\D	**N1**	**N2**	**N3**	**N4**	**N5**	**N6**	**N7**	**N8**	**N9**	**N10**
N1	0	9512	3130	3516	3734	3620	14938	3564	4618	3366
N2	9512	0	4576	3696	3972	5060	6932	4266	6758	5222
N3	3130	4576	0	3834	4466	4448	3182	4824	3970	17572
N4	3516	3696	3834	0	14766	4202	4374	8208	3842	3562
N5	3734	3972	4466	14766	0	3982	4510	6738	3712	4122
N6	3620	5060	4448	4202	3982	0	3866	8042	12420	4360
N7	14938	6932	3182	4374	4510	3866	0	4128	4742	3322
N8	3564	4266	4824	8208	6738	8042	4128	0	5846	4386
N9	4618	6758	3970	3842	3712	12420	4742	5846	0	4092
N10	3366	5222	17572	3562	4122	4360	3322	4386	4092	0

Unit: kbps

Table 3. Installation cost of 10-Mbps channel links

S\D	**N1**	**N2**	**N3**	**N4**	**N5**	**N6**	**N7**	**N8**	**N9**	**N10**
N1		1896	2224	2282	2118	3180	1238	2674	3994	2176
N2	1896		1638	2272	2086	2422	2588	2358	2902	1520
N3	2224	1638		958	832	1168	2230	922	1988	320
N4	2282	2272	958		396	1392	1900	678	2340	1062
N5	2118	2086	832	396		1434	1814	778	2372	924
N6	3180	2422	1168	1392	1434		3044	934	1150	1240
N7	1238	2588	2230	1900	1814	3044		2374	3968	2242
N8	2674	2358	922	678	778	934	2374		1882	1040
N9	3994	2902	1988	2340	2372	1150	3968	1882		2022
N10	2176	1520	320	1062	924	1240	2242	1040	2022	

4.2 Results

It is assumed that the organization determines to use MST (α = 0) as the core tree in both ordinary MENTOR-II and smart MENTOR-II. For the given requirements, MST consists of 9 branches: (1,7), (5,7), (3,5), (3,10), (2,10), (4,5), (4,8), (6,8), and (6,9).

4.3 Ordinary MENTOR-II

The ordinary MENTOR-II algorithm runs for all possible values of ρ and s to find a combination that gives the least installation cost while the network delay and link delay are within desired ranges. Since both ρ and s are real numbers that range between 0 and 1, it is not possible to perform an exhaustive search for all possible combinations of them. However, the suboptimum search can be performed as follows. First, ρ and s is initialized to 0.01. Then, they are increased by 0.01 at a time till the maximum value which is set to 0.99.

Figure 2 is shown the resulting network with ρ = 0.73 and s = 0.93. It achieves a minimum cost of 36,027.29. The network has 12 links of which utilization, load, and capacity are shown in Table 4.

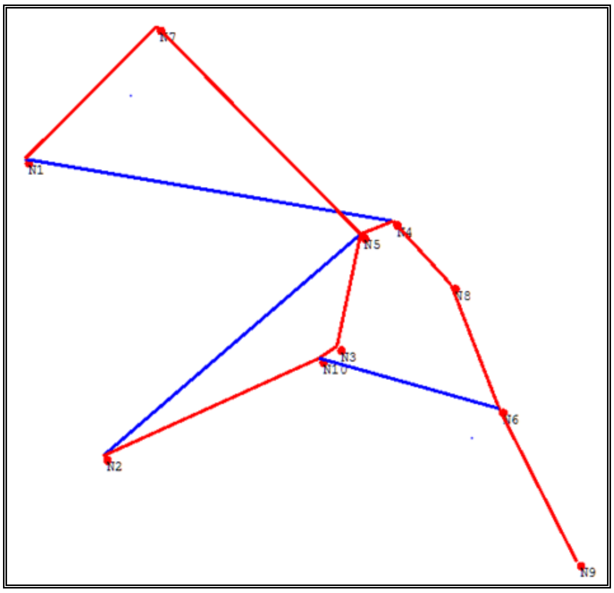

Figure 2. Network designed by the ordinary MENTOR-II

Table 4. Utilization, load, and capacity of the installed links

[x,y]	U[x,y]	load[x,y]	C[x,y]	[x,y]	U[x,y]	load[x,y]	C[x,y]
[1,4]	0.69	35,188	51,200	[4,5]	0.69	91,258	133,120
[4,1]	0.70	36,084	51,200	[5,4]	0.69	91,258	133,120
[1,7]	0.49	15,066	30,720	[4,8]	0.68	69,594	102,400
[7,1]	0.49	15,066	30,720	[8,4]	0.67	69,082	102,400
[2,5]	0.70	28,506	40,960	[5,7]	0.70	36,080	51,200
[5,2]	0.71	29,018	40,960	[7,5]	0.69	35,184	51,200
[2,10]	0.71	21,744	30,720	[6,8]	0.65	46,728	71,680
[10,2]	0.72	22,128	30,720	[8,6]	0.66	47,112	71,680
[3,5]	0.63	38,450	61,440	[6,9]	0.71	51,152	71,680
[5,3]	0.63	38,834	61,440	[9,6]	0.70	50,128	71,680
[3,10]	0.70	50,092	71,680	[6,10]	0.71	28,944	40,960
[10,3]	0.70	49,836	71,680	[10,6]	0.71	29,072	40,960

4.4 Smart MENTOR-II

The design procedure of the proposed algorithm is somewhat similar to that of the ordinary MENTOR-II except that the search domain of maximum link utilization is limited to all possible values in $(0, \Lambda_1)$. Since the required link delay T is 1.715, we have Λ_1 = 0.3 from (3). An algorithm means the computational complexity of the smart MENTOR-II is about one-third of that of the ordinary one.

The figure 3 is shown the resulting network with ρ_1 = 0.28 and s = 0.40. It achieves a minimum cost of 30,368.98. The maximum link utilization for various capacities is listed in Table 5. The network has 20 links of which utilization, load, and capacity as shown in Table 6.

Table 5. Maximum link utilization based on capacity

Number of 10-Mbps Channels (x)	1	2	3	4	5	6	7	8	9	10
ρ_x	0.28	0.64	0.76	0.82	0.86	0.88	0.90	0.91	0.92	0.93

Table 6. Utilization, load, and capacity of the installed links

[x,y]	U[x,y]	load[x,y]	C[x,y]	[x,y]	U[x,y]	load[x,y]	C[x,y]
[1,2]	0.65	20,066	30,720	**[4,8]**	0.72	29,510	40,960
[2,1]	0.65	20,066	30,720	**[8,4]**	0.72	29,510	40,960
[1,5]	0.46	14,072	30,720	**[4,10]**	0.53	16,388	30,720
[5,1]	0.47	14,456	30,720	**[10,4]**	0.53	16,260	30,720
[1,6]	0.41	8,366	20,480	**[5,7]**	0.56	11,398	20,480
[6,1]	0.41	8,494	20,480	**[7,5]**	0.54	11,142	20,480
[1,7]	0.72	22,126	30,720	**[5,8]**	0.77	31,622	40,960
[7,1]	0.72	21,998	30,720	**[8,5]**	0.77	31,622	40,960
[2,8]	0.46	9,454	20,480	**[5,10]**	0.57	11,672	20,480
[8,2]	0.47	9,582	20,480	**[10,5]**	0.57	11,672	20,480
[2,10]	0.68	27,846	40,960	**[6,7]**	0.43	8,864	20,480
[10,2]	0.69	28,230	40,960	**[7,6]**	0.43	8,736	20,480
[3,5]	0.68	27,982	40,960	**[6,8]**	0.74	30,222	40,960
[5,3]	0.70	28,750	40,960	**[8,6]**	0.75	30,862	40,960
[3,10]	0.73	22,276	30,720	**[6,9]**	0.72	22,164	30,720
[10,3]	0.73	22,404	30,720	**[9,6]**	0.71	21,908	30,720
[4,5]	0.72	22,244	30,720	**[8,9]**	0.58	17,882	30,720
[5,4]	0.73	22,500	30,720	**[9,8]**	0.57	17,498	30,720
[4,7]	0.43	8,758	20,480	**[9,10]**	0.54	10,978	20,480
[7,4]	0.42	8,630	20,480	**[10,9]**	0.54	11,106	20,480

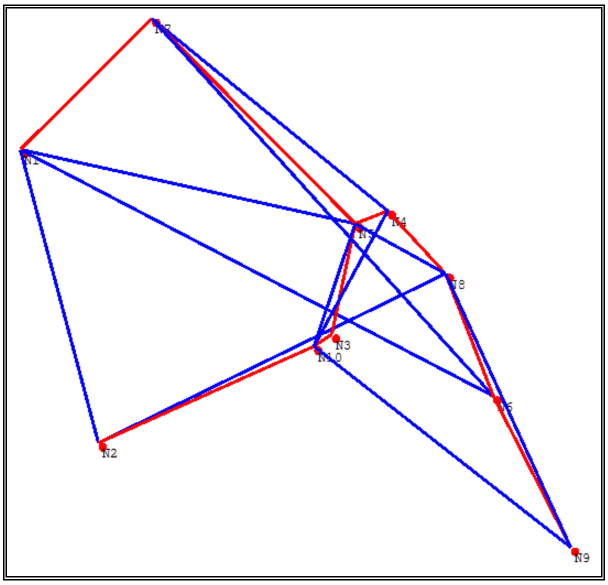

Figure 3. Network designed by the smart MENTOR-II

5. Performance evaluation

5.1 Setup

To evaluate the efficiency of the smart MENTOR-II, we analyze some design results for synthesized requirements regarding installation cost with various delay constraints. To explore the effect of the number of nodes on network performance, 10-node, 15-node, and 20-node groups are generated, and each group consists of 10 different design requirement sets. Each requirement set, which is synthesized by a design tool called DELITE [14], includes a random node distribution and the associated traffic demand matrices.

For all node distributions, the maximum node distance is limited to 100 km. The unicast traffic demands for each requirement set are also generated by DELITE with the following assumptions:

1) All nodes have the same total amount of unicast traffic in and unicast traffic out, denoted by $Traff$;

2) The unicast traffic between any pair of nodes is inversely proportional to the distance between them.

The effect of the amount of traffic on the design performance, traffic demand matrices as of 50 Mbps, 100 Mbps, and 200 Mbps are generated for each node distribution. Let for the network traffic including unicast be 10,240 bits.

Assume that one or more 10-Mbps channels can be installed in a link, and for each channel, the fixed installation cost is 250 unit and the variable installation cost is 2 unit per km. For each requirement set, the suboptimum search described in the previous section is performed to find the minimum cost for a maximum end-to-end delay of 5 ms and maximum link delays of 1.715 ms, 3 ms, and 5 ms, i.e., Λ_1 = 0.3, 0.6, 0.76, respectively.

5.2 Results

The tables 7-15 present the results obtained by the ordinary MENTOR-II and the modified one for nine combinations of three different traffic volumes, i.e., $Traff$ = 50 Mbps, 100 Mbps, 200 Mbps, and three different link delay requirements, i.e., 1.71 ms, 3 ms, and 5 ms.

Table 7. Results for $T = 1.715$ ms $(\Lambda_1 = 0.3)$ and $Traff = 50$ Mbps

	Ordinary MENTOR-II		**Smart MENTOR-II**		**Cost**	
Network	ρ	s	ρ_1	s	**Ordinary MENTOR-II**	**Smart MENTOR-II**
10n-1	0.73	0.94	0.12	0.30	34,887.19	31,446.08
10n-2	0.73	0.93	0.15	0.29	36,027.29	30,368.98
10n-3	0.81	0.97	0.21	0.37	32,627.71	30,296.31
10n-4	0.81	0.94	0.18	0.27	33,198.99	30,686.68
10n-5	0.70	0.84	0.06	0.12	37,771.04	31,913.79
10n-6	0.79	0.85	0.06	0.09	34,472.41	31,853.72
10n-7	0.75	0.94	0.04	0.15	35,142.45	30,684.23
10n-8	0.79	0.98	0.08	0.06	34,682.45	28,582.40
10n-9	0.82	0.96	0.21	0.12	34,207.86	30,351.13
10n-10	0.82	0.94	0.15	0.30	34,120.79	30,926.58
Average 10					**34,713.82**	**30,710.99**
15n-1	0.78	0.97	0.12	0.11	65,483.33	51,992.37
15n-2	0.70	0.95	0.08	0.26	64,360.14	54,368.94
15n-3	0.77	0.95	0.04	0.31	59,280.95	57,666.55
15n-4	0.73	0.92	0.14	0.25	61,296.54	53,344.41
15n-5	0.70	0.84	0.12	0.17	56,121.70	50,919.19
15n-6	0.72	0.96	0.11	0.33	64,583.81	56,315.37
15n-7	0.71	0.95	0.09	0.36	62,139.69	52,235.30
15n-8	0.76	0.98	0.11	0.12	64,042.71	48,937.85
15n-9	0.73	0.96	0.13	0.35	60,861.57	55,115.65
15n-10	0.02	0.12	0.02	0.12	50,763.14	50,763.14
Average 15					**60,893.36**	**53,165.88**
20n-1	0.70	0.96	0.11	0.49	94,930.63	79,940.10
20n-2	0.70	0.97	0.04	0.40	109,442.30	77,317.69
20n-3	0.78	0.97	0.08	0.30	89,418.70	77,744.28
20n-4	0.67	0.97	0.06	0.27	102,415.00	78,825.55
20n-5	0.68	0.95	0.10	0.35	97,181.30	78,957.90
20n-6	0.76	0.97	0.12	0.28	91,542.84	75,411.66
20n-7	0.68	0.94	0.04	0.25	92,195.90	75,022.70
20n-8	0.74	0.97	0.11	0.41	98,989.09	79,575.03
20n-9	0.70	0.96	0.04	0.24	93,472.37	76,080.09
20n-10	0.72	0.96	0.06	0.20	90,520.70	74,813.70
Average 20					**96,010.88**	**77,368.87**

Table 8. Results for $T = 1.715$ ms $(\Lambda_1 = 0.3)$ and $Traff = 100$ Mbps

	Ordinary MENTOR-II		**Smart MENTOR-II**		**Cost**	
Network	ρ	s	ρ_1	s	**Ordinary MENTOR-II**	**Smart MENTOR-II**
10n-1	0.91	0.98	0.08	0.11	59,491.75	51,618.72
10n-2	0.75	0.89	0.21	0.22	59,155.07	48,784.02
10n-3	0.63	0.69	0.23	0.18	57,515.76	48,799.00
10n-4	0.80	0.88	0.11	0.14	56,557.68	50,907.74
10n-5	0.70	0.78	0.04	0.09	60,459.81	51,850.12
10n-6	0.81	0.95	0.12	0.24	59,524.27	51,658.84
10n-7	0.88	0.96	0.13	0.15	61,679.71	48,638.96
10n-8	0.90	0.97	0.12	0.18	56,913.93	49,653.93
10n-9	0.73	0.94	0.15	0.13	59,321.41	51,700.47
10n-10	0.87	0.98	0.20	0.19	58,945.44	50,704.37
Average 10					**58,956.48**	**50,431.62**
15n-1	0.85	0.98	0.02	0.09	110,516.30	87,656.30
15n-2	0.77	0.98	0.09	0.21	106,826.40	88,005.56
15n-3	0.82	0.96	0.07	0.20	105,647.90	90,914.31
15n-4	0.87	0.97	0.03	0.17	111,301.50	87,665.00
15n-5	0.78	0.96	0.10	0.13	99,402.59	82,597.08
15n-6	0.70	0.95	0.03	0.08	114,581.70	92,341.27
15n-7	0.83	0.97	0.03	0.24	104,674.10	84,152.57
15n-8	0.68	0.95	0.04	0.16	105,307.90	83,746.66
15n-9	0.75	0.97	0.11	0.43	109,717.30	94,336.63
15n-10	0.67	0.88	0.08	0.11	103,602.70	84,256.05
Average 15					**107,157.84**	**87,567.14**
20n-1	0.77	0.97	0.01	0.15	158,634.50	123,948.60
20n-2	0.72	0.97	0.01	0.17	159,959.20	120,630.90
20n-3	0.79	0.97	0.04	0.16	151,851.50	122,232.80
20n-4	0.76	0.97	0.07	0.16	159,208.40	123,854.80
20n-5	0.74	0.98	0.07	0.05	173,231.30	132,648.30
20n-6	0.85	0.99	0.04	0.10	157,494.60	119,436.10
20n-7	0.70	0.97	0.10	0.24	154,639.00	118,381.60
20n-8	0.79	0.97	0.03	0.18	155,697.70	124,535.80
20n-9	0.79	0.97	0.18	0.31	153,890.00	125,293.10
20n-10	0.83	0.96	0.08	0.23	156,028.50	121,328.50
Average 20					**158,063.47**	**123,229.05**

Table 9. Results for $T = 1.715$ ms $(\Lambda_1 = 0.3)$ and $Traff = 200$ Mbps

	Ordinary MENTOR-II		**Smart MENTOR-II**		**Cost**	
Network	ρ	s	ρ_1	s	**Ordinary MENTOR-II**	**Smart MENTOR-II**
10n-1	0.85	0.95	0.05	0.29	101,121.70	86,032.13
10n-2	0.71	0.72	0.06	0.22	97,692.93	84,535.94
10n-3	0.73	0.95	0.21	0.17	106,008.90	81,416.01
10n-4	0.91	0.97	0.10	0.15	102,860.30	86,813.88
10n-5	0.70	0.91	0.09	0.14	107,576.30	86,403.66
10n-6	0.89	0.97	0.13	0.47	102,988.90	89,993.66
10n-7	0.86	0.97	0.10	0.11	105,613.60	86,517.41
10n-8	0.83	0.96	0.13	0.18	102,781.80	84,902.51
10n-9	0.71	0.73	0.16	0.23	97,825.80	89,403.36
10n-10	0.85	0.96	0.21	0.19	102,046.80	87,331.73
Average 10					**102,651.70**	**86,335.03**
15n-1	0.93	0.98	0.01	0.22	181,565.70	153,366.60
15n-2	0.90	0.99	0.14	0.10	179,082.50	146,707.10
15n-3	0.72	0.96	0.02	0.10	200,360.30	154,377.90
15n-4	0.82	0.97	0.01	0.11	188,468.90	148,541.80
15n-5	0.90	0.99	0.12	0.10	178,222.40	148,418.40
15n-6	0.66	0.96	0.07	0.10	209,886.00	150,968.50
15n-7	0.60	0.77	0.09	0.19	181,601.60	141,567.70
15n-8	0.69	0.90	0.04	0.08	178,344.90	142,380.10
15n-9	0.22	0.26	0.22	0.26	149,625.60	149,625.60
15n-10	0.93	0.99	0.24	0.23	183,820.00	140,293.60
Average 15					**183,097.79**	**147,624.73**
20n-1	0.87	0.99	0.28	0.26	288,545.80	199,088.70
20n-2	0.92	0.99	0.17	0.21	265,786.80	196,319.40
20n-3	0.83	0.99	0.24	0.20	317,927.00	206,851.10
20n-4	0.72	0.96	0.24	0.25	277,634.20	202,391.60
20n-5	0.89	0.99	0.17	0.20	284,665.80	201,683.40
20n-6	0.76	0.97	0.21	0.23	281,701.20	200,173.00
20n-7	0.87	0.99	0.21	0.19	272,745.60	198,961.50
20n-8	0.70	0.91	0.22	0.30	271,276.80	204,062.90
20n-9	0.76	0.97	0.28	0.28	289,817.80	203,517.10
20n-10	0.85	0.98	0.20	0.23	269,440.30	203,879.80
Average 20					**281,954.13**	**201,692.85**

From Tables 7-12, we can observe that, for maximum link delays of 1.715 and 3 ms, the network cost incurred by the smart MENTOR-II is always less than that incurred by the ordinary MENTOR-II. Also, it can be seen from Tables 13-15 that, for a maximum link delay of 5 ms, i.e., when the required link delay equals to the maximum end-to-end delay, there are 79 cases (out of 90 cases) where the smart MENTOR-II yields better performance. Considering the average installation cost of 27 groups classified by T, $Traff$, and the number of nodes, the smart MENTOR-II is superior to the ordinary one.

Table 10. Results for $T = 3$ ms ($\Lambda_1 = 0.6$) and $Traff = 50$ Mbps

Network	Ordinary MENTOR-II		Smart MENTOR-II		Cost	
	ρ	s	ρ_1	s	Ordinary MENTOR-II	Smart MENTOR-II
10n-1	0.78	0.78	0.39	0.13	30,161.26	28,798.49
10n-2	0.67	0.85	0.39	0.17	31,385.74	28,377.47
10n-3	0.74	0.86	0.52	0.31	30,106.89	27,508.46
10n-4	0.79	0.87	0.45	0.20	30,405.42	28,213.82
10n-5	0.69	0.80	0.49	0.22	32,657.52	28,162.08
10n-6	0.79	0.77	0.52	0.26	30,827.82	29,069.79
10n-7	0.75	0.92	0.37	0.12	32,725.44	28,552.80
10n-8	0.77	0.83	0.48	0.34	30,517.41	27,269.08
10n-9	0.82	0.95	0.58	0.37	33,100.00	28,912.41
10n-10	0.77	0.92	0.20	0.15	34,033.22	29,160.31
Average 10					**31,592.07**	**28,402.47**
15n-1	0.76	0.96	0.49	0.32	57,860.46	51,775.32
15n-2	0.77	0.89	0.20	0.19	56,828.19	49,944.96
15n-3	0.77	0.95	0.22	0.30	59,280.95	54,648.11
15n-4	0.73	0.91	0.42	0.30	60,118.92	51,129.56
15n-5	0.70	0.84	0.32	0.15	56,121.70	49,635.13
15n-6	0.76	0.93	0.21	0.24	57,160.23	54,043.84
15n-7	0.77	0.94	0.48	0.48	54,195.08	51,429.17
15n-8	0.74	0.95	0.13	0.35	57,806.19	55,115.65
15n-9	0.76	0.96	0.13	0.35	59,712.71	55,115.65
15n-10	0.72	0.95	0.50	0.33	58,673.05	49,162.85
Average 15					**57,775.75**	**52,200.02**
20n-1	0.68	0.90	0.02	0.43	84,782.94	81,533.15
20n-2	0.72	0.94	0.04	0.40	80,421.63	77,317.69
20n-3	0.78	0.97	0.08	0.30	89,418.70	77,744.28
20n-4	0.68	0.96	0.09	0.33	92,266.34	77,674.34
20n-5	0.71	0.94	0.08	0.26	90,605.91	77,273.58
20n-6	0.73	0.95	0.12	0.28	86,132.90	75,411.66
20n-7	0.74	0.97	0.04	0.25	87,507.04	75,022.70
20n-8	0.71	0.98	0.11	0.41	92,823.38	79,575.03
20n-9	0.70	0.94	0.04	0.24	87,379.28	76,080.09
20n-10	0.72	0.93	0.06	0.20	85,793.77	74,813.70
Average 20					**87,713.19**	**77,244.62**

Table 11. Results for $T = 3$ ms ($\Lambda_1 = 0.6$) and $Traff = 100$ Mbps

Network	Ordinary MENTOR-II		Smart MENTOR-II		Cost	
	ρ	s	ρ_1	s	Ordinary MENTOR-II	Smart MENTOR-II
10n-1	0.75	0.87	0.52	0.15	53,100.91	45,568.93
10n-2	0.78	0.81	0.59	0.47	53,939.52	46,735.53
10n-3	0.88	0.97	0.54	0.21	53,935.42	44,782.13
10n-4	0.81	0.82	0.49	0.22	54,086.53	48,565.01
10n-5	0.70	0.86	0.49	0.21	57,026.52	47,137.84
10n-6	0.84	0.94	0.46	0.23	54,749.67	47,906.80
10n-7	0.78	0.94	0.55	0.22	54,386.51	45,762.21
10n-8	0.78	0.86	0.60	0.33	49,742.27	45,027.44
10n-9	0.71	0.67	0.47	0.22	56,718.08	48,981.94
10n-10	0.83	0.90	0.42	0.22	52,362.77	48,840.60
Average 10					**54,004.82**	**46,930.84**
15n-1	0.73	0.89	0.55	0.39	100,474.70	81,837.34
15n-2	0.87	0.95	0.32	0.30	93,804.73	84,014.48
15n-3	0.82	0.79	0.24	0.24	89,543.30	86,507.46
15n-4	0.83	0.94	0.54	0.32	97,095.74	80,494.41
15n-5	0.76	0.92	0.45	0.29	96,326.50	78,765.52
15n-6	0.81	0.89	0.55	0.36	94,434.59	82,503.82
15n-7	0.78	0.94	0.30	0.18	95,893.71	78,447.09
15n-8	0.81	0.88	0.56	0.34	82,841.72	76,732.61
15n-9	0.76	0.85	0.44	0.32	100,221.40	82,620.00
15n-10	0.72	0.86	0.50	0.31	96,679.88	79,592.63
Average 15					**94,731.63**	**81,151.54**
20n-1	0.79	0.95	0.13	0.21	146,176.40	119,743.40
20n-2	0.78	0.94	0.23	0.18	139,091.40	116,232.20
20n-3	0.79	0.91	0.31	0.26	146,691.20	120,198.80
20n-4	0.63	0.88	0.24	0.21	149,079.80	118,535.50
20n-5	0.77	0.96	0.21	0.13	151,191.30	119,175.00
20n-6	0.76	0.93	0.53	0.37	144,333.80	113,805.00
20n-7	0.82	0.97	0.25	0.21	135,165.20	115,542.90
20n-8	0.73	0.90	0.45	0.43	136,227.80	123,941.40
20n-9	0.80	0.94	0.33	0.28	148,328.50	122,385.30
20n-10	0.83	0.95	0.26	0.28	138,886.90	120,908.80
Average 20					**143,517.23**	**119,046.83**

Table 12. Results for $T = 3$ ms ($\Lambda_1 = 0.6$) and $Traff = 200$ Mbps

Network	Ordinary MENTOR-II		Smart MENTOR-II		Cost	
	ρ	s	ρ_1	s	Ordinary MENTOR-II	Smart MENTOR-II
10n-1	0.93	0.93	0.56	0.28	91,632.61	77,818.98
10n-2	0.77	0.60	0.57	0.33	89,368.18	78,168.19
10n-3	0.84	0.66	0.58	0.19	81,346.20	75,334.55
10n-4	0.80	0.60	0.52	0.27	88,867.10	79,583.79
10n-5	0.77	0.60	0.52	0.31	90,187.24	80,277.55
10n-6	0.84	0.82	0.41	0.30	93,590.48	82,926.47
10n-7	0.78	0.71	0.57	0.27	88,852.26	77,578.88
10n-8	0.91	0.90	0.51	0.23	85,184.91	76,491.09
10n-9	0.77	0.60	0.56	0.29	88,912.30	79,883.21
10n-10	0.78	0.60	0.57	0.18	91,460.16	80,432.52
Average 10					**88,940.14**	**78,849.52**
15n-1	0.75	0.66	0.58	0.32	150,406.20	135,954.00
15n-2	0.69	0.66	0.42	0.21	154,387.30	136,447.40
15n-3	0.74	0.84	0.34	0.15	172,091.30	145,866.10
15n-4	0.73	0.62	0.52	0.31	149,099.40	134,379.50
15n-5	0.83	0.88	0.47	0.31	150,267.80	136,938.60
15n-6	0.69	0.76	0.53	0.46	170,472.90	137,561.60
15n-7	0.70	0.73	0.33	0.21	154,221.80	132,661.20
15n-8	0.79	0.86	0.58	0.27	155,619.60	129,289.30
15n-9	0.76	0.79	0.50	0.26	162,205.50	137,234.30
15n-10	0.87	0.95	0.41	0.24	148,990.50	132,717.10
Average 15					**156,776.23**	**135,904.91**
20n-1	0.75	0.89	0.50	0.32	235,659.50	190,130.40
20n-2	0.80	0.94	0.51	0.30	240,645.10	187,667.20
20n-3	0.82	0.96	0.45	0.27	265,087.20	192,511.20
20n-4	0.70	0.87	0.52	0.33	242,992.40	189,349.50
20n-5	0.84	0.96	0.36	0.28	247,949.70	199,129.90
20n-6	0.77	0.93	0.37	0.22	248,351.90	188,221.70
20n-7	0.87	0.97	0.32	0.19	250,672.40	194,361.80
20n-8	0.78	0.94	0.18	0.20	260,751.60	203,824.20
20n-9	0.76	0.93	0.28	0.49	261,908.90	221,574.60
20n-10	0.85	0.89	0.29	0.22	216,163.50	197,507.00
Average 20					**247,018.22**	**196,427.75**

Table 13. Results for $T = 5$ ms ($\Lambda_1 = 0.76$) and $Traff = 50$ Mbps

Network	Ordinary MENTOR-II		Smart MENTOR-II		Cost	
	ρ	s	ρ_1	s	Ordinary MENTOR-II	Smart MENTOR-II
10n-1	0.80	0.61	0.62	0.38	28,677.95	27,934.61
10n-2	0.76	0.85	0.76	0.85	29,242.68	29,242.68
10n-3	0.72	0.60	0.52	0.31	29,978.84	27,508.46
10n-4	0.69	0.61	0.60	0.28	30,103.18	27,725.92
10n-5	0.74	0.60	0.49	0.22	31,008.53	28,162.08
10n-6	0.73	0.77	0.52	0.26	30,661.91	29,069.79
10n-7	0.71	0.76	0.37	0.12	30,022.09	28,552.80
10n-8	0.66	0.61	0.48	0.34	29,643.44	27,269.08
10n-9	0.69	0.68	0.61	0.36	31,197.63	28,097.17
10n-10	0.72	0.61	0.20	0.15	31,095.26	29,160.31
Average 10					**30,163.15**	**28,272.29**
15n-1	0.65	0.69	0.62	0.48	53,065.79	50,054.66
15n-2	0.67	0.68	0.20	0.19	51,498.90	49,944.96
15n-3*	0.69	0.62	0.22	0.30	53,930.68	54,648.11
15n-4	0.67	0.61	0.56	0.33	53,876.00	49,240.11
15n-5	0.65	0.72	0.32	0.15	53,333.38	49,635.13
15n-6*	0.66	0.69	0.21	0.24	52,380.27	54,043.84
15n-7*	0.73	0.70	0.48	0.48	47,325.53	51,429.17
15n-8	0.70	0.71	0.11	0.12	52,678.56	48,937.85
15n-9	0.67	0.66	0.13	0.35	55,337.79	55,115.65
15n-10	0.70	0.60	0.50	0.33	51,512.82	49,162.85

Average 15					**52,493.97**	**51,221.23**
20n-1*	0.62	0.62	0.11	0.49	78,864.95	79,940.10
20n-2	0.64	0.82	0.04	0.40	80,371.13	77,317.69
20n-3	0.67	0.63	0.08	0.30	77,861.16	77,744.28
20n-4	0.60	0.68	0.09	0.33	79,044.76	77,674.34
20n-5*	0.69	0.61	0.08	0.26	76,855.30	77,273.58
20n-6*	0.69	0.63	0.12	0.28	73,903.36	75,411.66
20n-7	0.60	0.64	0.04	0.25	77,638.38	75,022.70
20n-8*	0.70	0.92	0.11	0.41	79,513.94	79,575.03
20n-9	0.60	0.87	0.04	0.24	83,801.99	76,080.09
20n-10	0.62	0.71	0.06	0.20	80,851.34	74,813.70
Average 20					**78,870.63**	**77,085.32**

Table 14. Results for $T = 5$ ms $(\Lambda_1 = 0.76)$ and $Traff = 100$ Mbps

Network	Ordinary MENTOR-II		Smart MENTOR-II		Cost	
	ρ	s	ρ_1	s	Ordinary MENTOR-II	Smart MENTOR-II
10n-1	0.83	0.89	0.58	0.17	51,052.14	44,605.33
10n-2	0.82	0.81	0.59	0.38	51,030.56	46,806.02
10n-3	0.79	0.86	0.66	0.35	49,383.38	44,279.88
10n-4	0.81	0.73	0.61	0.30	49,573.24	47,048.29
10n-5	0.76	0.60	0.71	0.45	51,616.14	47,021.02
10n-6	0.81	0.63	0.65	0.28	50,227.36	46,819.58
10n-7	0.76	0.67	0.55	0.22	50,993.21	45,762.21
10n-8	0.78	0.86	0.61	0.33	49,742.27	44,801.74
10n-9	0.76	0.71	0.47	0.22	52,199.08	48,981.94
10n-10	0.76	0.60	0.42	0.22	51,209.34	48,840.60
Average 10					**50,702.67**	**46,496.66**
15n-1	0.73	0.60	0.57	0.39	84,986.13	80,758.76
15n-2*	0.73	0.61	0.32	0.30	79,901.79	84,014.48
15n-3	0.82	0.79	0.24	0.24	89,543.30	86,507.46
15n-4	0.76	0.60	0.68	0.47	82,986.61	78,341.25
15n-5	0.75	0.60	0.45	0.29	83,224.34	78,765.52
15n-6	0.75	0.60	0.61	0.44	85,218.02	81,821.95
15n-7	0.79	0.64	0.30	0.18	79,984.70	78,447.09
15n-8	0.80	0.87	0.55	0.31	81,150.78	76,759.86
15n-9	0.76	0.60	0.57	0.37	84,958.77	82,000.80
15n-10	0.72	0.63	0.50	0.31	85,970.28	79,592.63
Average 15					**83,792.47**	**80,700.98**
20n-1	0.68	0.61	0.13	0.21	126,269.00	119,743.40
20n-2	0.68	0.69	0.23	0.18	122,966.50	116,232.20
20n-3	0.69	0.65	0.31	0.26	128,522.30	120,198.80
20n-4	0.72	0.77	0.24	0.21	128,096.90	118,535.50
20n-5	0.72	0.66	0.21	0.13	122,478.70	119,175.00
20n-6	0.78	0.69	0.58	0.45	116,714.80	112,604.60
20n-7	0.69	0.63	0.25	0.21	127,982.50	115,542.90
20n-8	0.72	0.77	0.45	0.43	132,037.40	123,941.40
20n-9	0.81	0.93	0.33	0.28	130,971.70	122,385.30
20n-10	0.74	0.60	0.26	0.28	123,185.00	120,908.80
Average 20					**126,226.64**	**118,926.79**

Table 15. Results for $T = 5$ ms $(\Lambda_1 = 0.76)$ and $Traff = 200$ Mbps

Network	Ordinary MENTOR-II		Smart MENTOR-II		Cost	
	ρ	s	ρ_1	s	Ordinary MENTOR-II	Smart MENTOR-II
10n-1	0.94	0.60	0.52	0.36	79,419.66	79,109.31
10n-2	0.88	0.60	0.73	0.35	78,581.46	72,663.63
10n-3	0.88	0.63	0.73	0.31	76,632.39	72,626.73
10n-4	0.90	0.60	0.70	0.34	78,736.25	76,160.30
10n-5	0.87	0.60	0.58	0.27	84,933.14	79,611.20
10n-6	0.88	0.60	0.71	0.35	85,274.83	78,476.62
10n-7	0.81	0.69	0.72	0.36	83,853.68	75,064.70
10n-8	0.90	0.70	0.66	0.25	77,338.48	74,542.78
10n-9*	0.88	0.60	0.67	0.38	77,444.20	78,219.13
10n-10*	0.92	0.73	0.64	0.18	79,558.13	80,042.09
Average 10					**80,177.22**	**76,651.65**
15n-1	0.75	0.66	0.58	0.32	150,406.20	134,374.90
15n-2	0.76	0.60	0.42	0.21	145,302.70	136,447.40
15n-3	0.86	0.82	0.34	0.15	153,168.20	145,866.10
15n-4	0.83	0.80	0.59	0.35	148,494.70	132,747.40
15n-5	0.85	0.82	0.63	0.34	142,406.30	136,211.40
15n-6*	0.78	0.80	0.68	0.37	151,906.10	134,185.50
15n-7	0.76	0.62	0.33	0.21	143,014.50	132,661.20
15n-8*	0.82	0.73	0.54	0.23	137,910.00	131,083.50
15n-9	0.76	0.65	0.65	0.39	154,404.50	135,442.10
15n-10	0.78	0.64	0.41	0.24	147,098.90	132,717.10
Average 15					**147,411.21**	**135,173.66**
20n-1	0.75	0.60	0.50	0.32	204,027.00	190,130.40
20n-2	0.74	0.68	0.51	0.30	218,504.90	187,667.20
20n-3	0.75	0.60	0.45	0.27	201,869.80	192,511.20
20n-4	0.68	0.60	0.52	0.33	222,696.40	189,349.50
20n-5	0.74	0.64	0.36	0.28	207,913.60	199,129.90
20n-6	0.73	0.60	0.37	0.22	205,100.00	188,221.70
20n-7	0.74	0.86	0.32	0.19	229,148.00	194,361.80
20n-8	0.68	0.60	0.53	0.37	223,163.20	200,095.70
20n-9*	0.73	0.67	0.13	0.05	210,193.70	219,770.70
20n-10	0.85	0.89	0.29	0.22	216,163.50	197,507.00
Average 20					**213,878.01**	**195,874.51**

To gain a better understanding, let us define the normalized design margin as

$$Margin = \frac{Cost_{OM} - Cost_{MM}}{Cost_{OM}} \qquad (6)$$

$Cost_{OM}$ and $Cost_{MM}$ are the cost of the network designed by the ordinary MENTOR-II and that of the network designed by the smart MENTOR-II, respectively. Figures 4-6 as shown the normalized design margins for 10-node, 15-node, and 20-node networks, respectively. According to these figures, it can be concluded as follows. First, the design margins decrease as the maximum link delay approaches the maximum end-to-end delay. Second, the design margins grow as the traffic volume increases from 50 Mbps to 100 Mbps, but some of them decline after that, i.e., the design margins for maximum link delays of 3 ms and 5 ms as shown in Figure 4.

Therefore, the smart MENTOR-II tends to have better performance regarding installation cost, especially when the maximum link delay is smaller than the maximum end-to-end delay. For the case where the former delay is close or equals to the latter delay, most of the networks designed by the smart MENTOR-II achieve lower cost but with less margin. It is noteworthy that the smart MENTOR-II always has less complexity regarding search space.

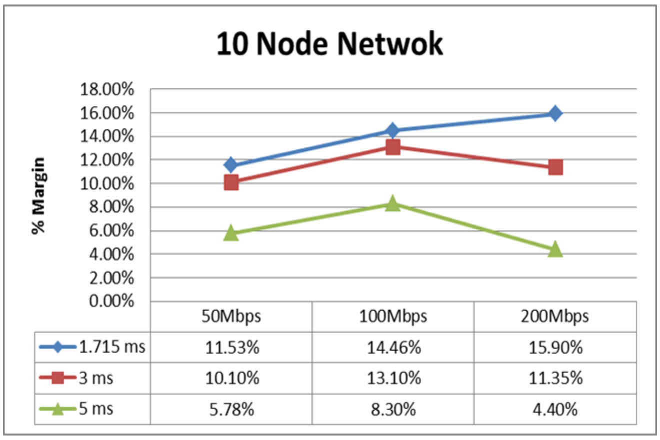

Figure 4. Normalized design margin for 10-node network with a maximum end-to-end delay of 5 ms

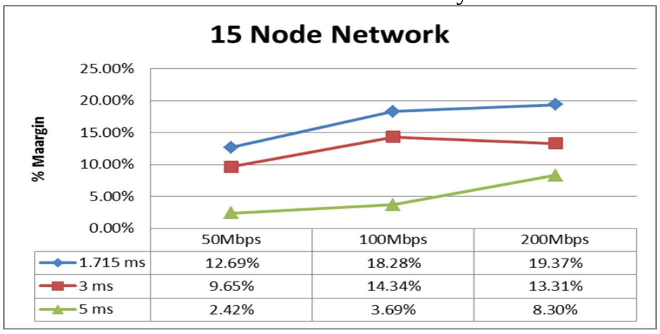

Figure 5. Normalized design margin for 15-node network with a maximum end-to-end delay of 5 ms

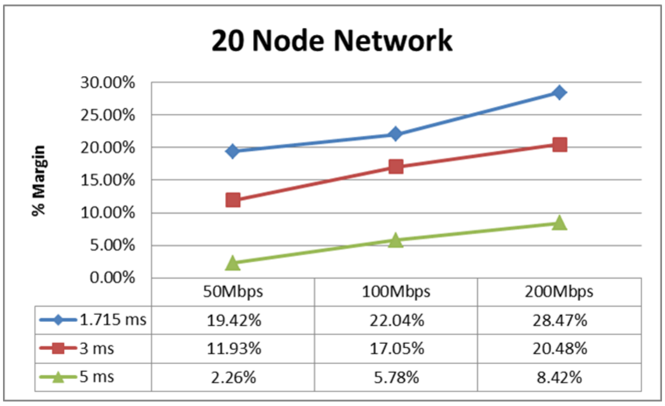

Figure 6. Normalized design margin for 20-node network with a maximum end-to-end delay of 5 ms

6. Conclusions

In this paper, the smart routing algorithm design to cope with delay constraints for communication networks that can be represented by M/M/1 model, the upper limit of maximum link utilization has been introduced in the smart MENTOR-II for supporting the IoT devices. One main advantage of this algorithm over the ordinary MENTOR-II is that the computational complexity regarding search space can be reduced by factor Λ_1, i.e., the upper limit of maximum link utilization for a single-channel link. To evaluate the performance of the proposed algorithm, various distributions of 10, 15, and 20 network have been generated. In comparison with the ordinary MENTOR-II, it is found that the network designed by the smart MENTOR-II tends to yield better performance regarding installation cost, especially when the maximum link delay is smaller than the maximum end-to-end delay.
This routing performance improvement tends to decrease as the former delay approaches the latter delay. However, the majority of networks designed by the smart MENTOR-II still achieve lower installation cost when the maximum link delay is close or equals to the maximum end-to-end delay.

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