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Heuristics for Multicast Routing and Wavelength Assignment with Delay Constraint in WDM Network with Heterogeneous Capability

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Abstract- *Because optical* WDM *network will become a real choice to build up backbone in the future, the multicasting in* WDM *network should be supported for various network applications. In this paper, the new* Multicast Routing and Wavelength Assignment with Delay Constraint (MRWA-DC) *problem is introduced. Since this problem can be reduced to the* Minimal Steiner Tree Problem*, an NP-Complete problem, an integrated 2-Level solution model which is an iterative process consisting of* Selecting Wavelength Procedure (SWP) *with two evaluation functions (*MaxE *and* MinR*) and* Finding Assigned Light-tree Procedure (WALP) *with two heuristics* (MaxDepth *and* MaxDest) *is proposed to solve the problem. According to experimental results, the solutions found by the 2-Level solution model are approximated equal to the solutions found by* ILP *formulation.*

Keywords: WDM, multicast wavelength assignment

1. Introduction

The technology *WDM* network [1] provides connectivity among optical components to make optical communication meet the increasing demands for high channel bandwidth and low communication delay. The utilization of wavelength to route data is referred as *wavelength routing*. In the *wavelength-routing WDM* network, data can be routed to other optical switches based on wavelengths of optical fibers. If the transmission between the input port and the output port of a switch can use two different wavelengths, the switch needs to have the capacity of wavelength conversion. In *WDM* network, a *light-path* would be set up to carry data among switches at wavelength level without optical-to-electrical conversion. According to the trail of the light-path, the cost of utilized wavelength and the delay time of transmitting optical signal to route data to a destination are referred as the *communication cost* and the *transmission delay* of the light-path, respectively. The communication cost may be the numbers of fibers and switches or the costs of fibers and switches used to establish the connection.

Many new network applications, such as videoconferencing, video on demand system, and so on, have generated new demand of communication model. *Multicasting* is a type of important model used to send data (messages) from a single source to multiple destinations. As for providing the communication model, a switch with or without *light splitting capability*, referred as an *MC* (*multicast capable*) node or an *MI* (*multicast incapable*) node [3], can or can not split a (optical) signal of input port to multiple signals of output port without optical-to-electrical conversions, where these split signals can be transmitted to other switches concurrently. The route of connecting the source and destinations is referred as a *routing-tree*. The *light splitting capacity* of a switch is used to describe the maximal number of split signals in output port. Using *MC* nodes to route data to several destinations would have significant wavelength saving. The internal node in a routing-tree with or without the feature that the number of outgoing edges isn't greater than its light splitting capacity is referred as a *feasible branch* or an *infeasible branch*. A routing-tree without *infeasible branch* is referred as a *light-tree* [2] which needs one wavelength to route data to these nodes connected by these outgoing edges. If all nodes in network are *MC* nodes, one light-tree may be enough to route data to all destinations; otherwise, a set of light-trees referred as a *light-forest* may be required and the network has *sparse light splitting*. In general, the network composed of nodes with different light splitting capacities is referred as the *WDM-He* (*WDM network with heterogeneous light splitting capability*) network.

Two measurements, communication cost and wavelength consumption, are usually discussed to evaluate the route for providing high *Quality of Service* (*QoS*). Moreover, to guarantee that video and audio signals can be efficiently transmitted in interactive multimedia application, transmission delays from the source to all destinations will be limited under a given delay bound, where the delay bound may be decided according to emergent degree, data priority, or application type of the data.

Therefore, transmitting data with delay bound is realistic to reflect the demand about data transmission in the future. Data is required to be transmitted from a source to multiple destinations is referred as a *request*. A *request with delay bound* represents that it need to be transmitted under a given delay bound. To reroute a request in the multicast scheme is referred as the *Multicast Routing and Wavelength Assignment* problem (*MRWA*).

To solve multicast routing problems, several heuristics [5, 7, 8] and *ILP* (Integer Linear Programming) formulations [3, 4, 6, 9, 10] have also been proposed in *WDM* network. In our survey, few studies seem to have been done on discussing the *MRWA* problems of routing a request with delay bound in *WDM-He* network with or without wavelength conversion, and seem to have token account of both communication cost and wavelength consumption in the object function. Therefore, the *Multicast Routing and Wavelength Assignment with Delay Constraint* (*MRWA-DC*) problem, finding an optimal light-forest with minimal multicast cost and assigning wavelengths to these light-trees for routing a request with a given delay bound in *WDM-He* network, was proposed in [9], where the multicast cost is the values of the *multicast cost function*. The *multicast cost function*, a linear combination of communication cost and wavelength consumption, α×(communication cost) + β×(wavelength consumption), was defined to respond the cost of rerouting a request, where α and β can be appropriately chosen according to the topology and the load of network. The *MRWA-DC* problem was solved by *ILP* formulation in [9], but the *ILP* formulation used to solve the problem in huge network may be very difficult and inefficient. According to previous experimental results, the execution time to reroute a request with 4 destinations in the network with 100 nodes might consume nearly 20 hours, and the *ILP* formulation couldn't be used to solve the problem in the network with more than 110 nodes or with great numbers of wavelengths and nodes in affordable execution time. Therefore, to propose an efficient heuristic seems necessary and important to solve the problem.

In this paper, the *MRWA-DC* problem will be solved by an integrated 2-Level solution model which is an iterative process consisting of two integrated procedures (*Selecting Wavelength Procedure* with two evaluation functions and *Finding Assigned Light-tree Procedure* with two heuristics). Three experiments are simulated to discuss the performance and efficiency of the solution model.

2. Problem formulation

In [9], a *WDM-He* network represented with a weighted graph $G(V, E)$, and the node set V and the edge set E represent the switches and directed optical links between two nodes, respectively. For each link connecting two nodes u and v denoted as $e_{u,v}$, $c(e_{u,v})$ and $d(e_{u,v})$ represent the communication cost and the transmission delay of $e_{u,v}$, respectively. M represents a set of available wavelengths in each link to provide the functionality of transmitting data. $\theta(v)$ represents the light splitting capacity of node v; that is, the node v is an *MC* node when $\theta(v) > 1$; otherwise, $\theta(v) = 1$.

A request with a delay bound Δ represented as $r(s, D=\{d_1, d_2, \ldots, d_m\}, \Delta)$ indicates that there is data originating from a certain source s, and the data is routed to all destinations d_i in D finally, where $s \in V$, $D \subseteq V\text{-}\{s\}$ is a set of destinations, $|D| = m$, and the transmission delay of routing data to each d_i must be bounded by the delay bound Δ. In this paper, we assume that Δ is a given value.

Suppose there are τ sub-trees ST_i with root s_i connecting s to form a routing-tree T with root s for $1 \le i \le \tau$. The *wavelength consumption* $\omega(T)$, *communication cost* $c(T)$, and *transmission delay* $d(T)$ of T are defined as follows, respectively.

$$\omega(T) = \begin{cases} 1 & T \text{ having a root node only} \\ \max\left(\left\lceil \dfrac{\sum_{1 \le i \le \tau} \omega(ST_i)}{\theta(s)} \right\rceil, \varpi(T)\right) & \text{otherwise} \end{cases},$$

$$\text{where } \varpi(T) = \max_{1 \le i \le \tau} \omega(ST_i)\ .$$

$$c(T) = \sum_{1 \le i \le \tau} (\omega(ST_i) \cdot c(e_{s,s_i}) + c(ST_i))$$

$$d(T) = \max_{1 \le i \le \tau}(d(ST_i) + d(e_{s,s_i}))$$

The usage status of the wavelength λ ($\lambda \in M$) in the edge e described with e^{λ} represents whether it has been used or not. That is, $e^{\lambda}=0$ shows that λ in e has been used to transmit some request; otherwise, $e^{\lambda}=1$. Therefore, the wavelength λ is named as a *w-feasible* wavelength in e when $e^{\lambda}=1$; in other words, e is named as a *w-feasible* edge in λ. When λ is a w-feasible wavelength in each $e \in T$, λ is a w-feasible wavelength for T. The node pair (T, λ) represents that the wavelength λ is assigned to T. Let $\Gamma=\{(T_1, \lambda_1), (T_2, \lambda_2), \ldots, (T_\omega, \lambda_\omega)\}$ for $r(s, D, \Delta)$ being an *assigned light-forest* must satisfy the following four conditions:

(1) *capacity constraint* : $out_{T_i}(u) \le \theta(u)$,

where $out_{T_i}(u)$ represents the number of outgoing edges of node u in T_i

(2) *delay constraint* : $d(T_i) \le \Delta,\ \forall\ i \in \omega$

(3) destination constraint : $D \subseteq \bigcup_{i=1}^{\omega}(V(T_i))$

(4) wavelength constraint :

$e^{\lambda_i}=1,\ \forall\ e \in T_i,\ \forall\ i \in \omega,\ \lambda_i \in M$.

To evaluate different assigned light-forests, the *multicast cost function* f to calculate multicast cost of Γ is defined as

$$f(\Gamma) = \alpha \cdot \sum_{T_i \in \Gamma} c(T_i) + \beta \cdot \omega\ .$$

According to the above definition, the *MRWA-DC* problem is equivalent to find an optimal assigned light-forest with minimal multicast cost to route a request under delay bound. When finding an optimal light-forest and assigning wavelength for each light-tree are processed independently, it is hard to choose a w-feasible wavelength for each light-tree. Furthermore, it may have a high possibility that no *w-feasible* wavelength can be found for some light-tree. The request is blocked because it is fail to be routed. Therefore, proposing integrated heuristics to regard the wavelength usage of each link in the process of finding a assigned light-forest is important and realistic. Suppose a *wavelength-based graph* of λ, $G(V, E^{\lambda})$, is defined as a graph by removing all edges which are not w-feasible edge in λ; that is, $E^{\lambda} = \{e| e\in E, e^{\lambda} = 1\}$. A light-tree T found from $G(V, E^{\lambda})$ can be viewed as that λ is a w-feasible wavelength to T, and the procedure used to find a light-tree covering some destinations from the wavelength-based graph of λ is equivalent to find an assigned light-tree of λ. The observation is applied in the paper to propose an integrated 2-Level solution model which is an iterative process consisting of *Selecting Wavelength Procedure* (*SWP*) and *Finding Assigned Light-tree Procedure* (*FALP*) to solve the *MRWA-DC* problem in polynomial time.

3. Solution Model

The solution model basically is an iterative process, and each iteration is to select a wavelength to construct wavelength-based graph and to find a light-tree from the wavelength-based graph. For a selected wavelength λ, the found light-tree is the assigned light-tree of λ used to reroute some destinations in the iteration. The other assigned light-trees used to route to the reminder of destinations need to be decided in the next iteration. When the process is executed again, the parts of the reminder will be rerouted by the assigned light-trees found in the iteration. To repeat the process till the reminder is empty, all destinations are rerouted by some assigned light-tree and the union of these light-trees will be an assigned light-forest which satisfies the 4 constraints defined in the Session 2. It is evident that the iterative process being a greedy approach can be used to solve the *MRWA-DC* problem.

According to the above discussion, the iterative process including two procedures: (1) *Selecting Wavelength Procedure* (*SWP*) choosing a wavelength to construct a wavelength-based graph, and (2) *Finding Assigned Light-tree Procedure* (*FALP*) finding a light-tree from the wavelength-based graph, is proposed. An assigned light-tree will be found in iteration, and an assigned light-forest is obtained when the iteration is terminated. In the *FALP*, two coupled problems, which destinations can be rerouted in the selected wavelength and how to find a light-tree under the delay bound to cover these destinations, induce finding optimal light-tree to be an NP-Complete problem. Furthermore, the found light-tree will not be adjusted again because how to adjust the light-tree based on previous found light-trees is another NP-Complete problem. For the additional cause that the order of selecting wavelength may affect the multicast cost by using the greedy approach, we may note that it is necessary to propose some heuristics in the *SWP* and in the *FALP*. In this paper, *Maximal W-Feasible Edges Assigning First* (*MaxE*) and *Minimal Requests Assigning First* (*MinR*) for *SWP* and *Maximal Depth Seserving First* (*MaxDepth*) and *Maximal Destinations Reserving First* (*MaxDest*) for *FALP* are proposed as follows.

3.1. Selecting Wavelength Procedure

An improper order of selecting wavelength may cause the *FALP* to find a set of local optimal assigned light-trees; furthermore, the solution is far from the optimal light-forest. It is necessary to propose some evaluation functions to evaluate each wavelength. When all assigned light-trees can always be found from the wavelength-based graph of the wavelengths with high value in iteration, the union of these assigned light-trees may be approximated to the optimal solution in high possibility

In the procedure, the *Eval*(λ) evaluation function will be used to give an evaluated value for each wavelength λ and the wavelength is selected according to *Eval*(λ). Nevertheless, the selecting is very hard to predict accurately or to compute the value in affordable execution time. Two simple greedy heuristics, *Maximal W-Feasible Edges Assigning First* (*MaxE*) and *Minimal Requests Assigning First* (*MinR*) are proposed as follows.

(1) *MaxE heuristic*

The *MaxE* heuristic is based on the assumption that the wavelength-based graph with more edges is advantageous to find a light-tree with less communication cost in higher possibility. The wavelength $\lambda_{opt} \in M'$ satisfying $|E^{\lambda\text{-}opt}| \geq |E^{\lambda}|$ for all $\lambda \in M'$ will be chosen first and the $Eval(\lambda)$ is defined as : $Eval(\lambda) = |E^{\lambda}|$, where $E^{\lambda} = \{e| e\in E, e^{\lambda} = 1\}$.

(2) *MinR heuristic*

A wavelength which has been used to route minimal number of requests represents its utility rate is the lowest than other wavelengths. The lower utility rate of wavelength selected first to route requests can balance the transmission load of wavelength to reduce the blocking rate. Therefore, the heuristic is proposed and defined as:

$Eval(\lambda)$ = the number of requests routed by using the wavelength λ

3.2. Finding Assigned Light-Tree procedure

In this procedure, the optimal light-tree with minimal communication cost is expected to be found. Nevertheless, finding the optimal light-tree is NP-complete discussed in [9] such that proposing an efficient heuristic to find a near optimal light-tree in polynomial time is more important than to find the optimal light-tree. In [9], the two heuristics used in *Generating Phase* and *Refining Phase* to find a light-forest with less multicast cost, and two critical light-paths *MCLP* (*Minimal Communication cost Light-Path*) $P^c(u, v)$ and *MDLP* (*Minimal transmission Delay Light-Path*) $P^d(u, v)$ which are two light-paths between u and v with minimal communication cost and with minimal transmission delay are utilized in the procedure. The procedure divided into three steps, *generating a candidate*, *refining the candidate*, and *cutting up infeasible branches* will be described as follows.

(1) *Generating a candidate*

All *MDLPs* between the source and all destinations need to be checked for the condition that their transmission delay must be smaller than or equal to the delay bound. A graph, constructed by merging these *MDLP*s which are satisfied the check condition is referred as a *weak candidate*. Because there is only one light-path with minimal transmission delay between two nodes, the weak candidate must be a tree.

(2) *Refining the weak candidate*

The refining process is also an iterative process which refines the light-path between two nodes to reduce multicast cost. The iteration consists of two processes, finding a node-pair (u, v) to be refined and rerouting the light-path between u and v. For the weak candidate $\hat{T}^d$ and x being the nearest common predecessor node of u and v, the rerouting process consists of eliminating $P_{\hat{T}^d}(x,u)$ from $\hat{T}^d$ and concatenating $P^c(v, u)$ to $\hat{T}^d$ to form a new graph $\hat{T}^n$, where the notation $P_{\hat{T}^d}(x,u)$ represents a path between x and u in $\hat{T}^d$; that is, $P_{\hat{T}^d}(u,v)$ is the path of concatenating $P_{\hat{T}^d}(x,u)$ and $P_{\hat{T}^d}(x,v)$. It is worth noting that the latter may cause cycles to be formed in $\hat{T}^n$ and the *Prim's Minimal Spanning Tree algorithm* needs to be applied to clean up the cycles. Nevertheless, which node-pair or how many node-pairs need to be rerouted is hard to recognize. Therefore, *cost-difference* (*CD*) of a node-pair (u, v), $CD(\hat{T}^d, u, v)$, is proposed to predict the expectation of the multicast cost promotion on rerouting u to v. The node-pair (u, v) having higher cost-difference value indicates that the rerouting from u to v may reduce multicast cost more efficient than others. The $CD(\hat{T}^d, u, v)$ is defined as

$$CD(\hat{T}^d,u,v)=\begin{cases}\alpha(c(P_{\hat{T}^d}(x,u))-c(P^c(v,u))), \\ \quad \text{if } out_{\hat{T}^d}(v)<\theta(v) \\ \alpha(c(P_{\hat{T}^d}(x,u))-c(P^c(v,u))-c(P_{\hat{T}^d}(s,v)))-\beta, \\ \quad \text{otherwise}\end{cases}$$

All node-pairs in the $\hat{T}^d$ are sorted in the decreasing order by the value of *cost-difference*. When $f(\hat{T}^n) < f(\hat{T}^d)$ and $d(\hat{T}^n) \le \Delta$ are satisfied, $\hat{T}^n$ will be a better weak candidate than $\hat{T}^d$. The multicast cost and execution time could be affected by the number and the choosing order of node-pairs. In this step, each node will try to reroute to its *nearest node*, where the *nearest node* of u, $\delta(u)$, is defined as the node with $CD(\hat{T}^d, u, \delta(u)) \le CD(\hat{T}^d, u, v)$ for all $v \in V\text{-}\{u\}$. The iteration will be terminated when no node-pair can be refined again.

(3) *Cutting up infeasible branches*

Some internal nodes may be infeasible branches such that the weak candidate may not be a light-tree. It is necessary to propose some heuristics to decide which nodes will be eliminated from the weak candidate to form a light-tree. In this step, the *reservation weight function*, *r-weight*, is defined to give a *reservation weight* for each node. Reserving the edge connecting the node with high *reservation weight* may reduce the multicast cost or the blocking rate of routing the request. Therefore, for v being an infeasible branch (i.e., $out_{\hat{T}^n}(v) > \theta(v)$), $out_{\hat{T}^n}(v) - \theta(v)$ outgoing edges whose *reservation weight* are smaller than others need to be cut out from $out_{\hat{T}^n}(v)$ outgoing edges of v. There are two different heuristics, *Maximal Depth Reserving First* (*MaxDepth*) and *Maximal Destinations Reserving First* (*MaxDest*), are defined for the *r-weight*. For routing the request to one destination by the light-path with maximal depth, it needs to use more links such that the destination may be more difficult to be rerouted by other sub-tree using other wavelength or have high probability to be blocked for needing more w-feasible edges. Therefore, the *MaxDepth* heuristic applies the heuristic such that these edges connecting these sub-trees with maximal depth are reserved. Nevertheless, in the *MaxDest* heuristic, it assumes that the sub-tree covering more destinations may indicate routing the request with fewer wavelengths.

4. Experiments

The approach used in this simulation to evaluate the performance of our solution model can be referred in Waxman [11]. In the approach, there are n nodes in network, these nodes are distributed randomly over a rectangular grid, and are placed on an integer coordinates. For a network topology generated for experiencing, each directed link between two nodes u and v is added with the probability function $P(u,v) = \lambda \exp(-p(u,v)/\gamma\delta)$, where $p(u, v)$ is the distance between u and v, δ is the maximum distance between each two nodes, and $0 < \lambda, \gamma \leq 1$.

The communication cost and the transmission delay of link (u, v) are defined as the distance between u and v on the rectangular coordinated grid and a randomly generated value between 0.1 and 3, respectively. For each experimental request $r(s, D, \Delta)$, s and D with different number of destinations are generated randomly. The notation of "m=4" would be used to represent a randomly generated request routed to 4 destinations. Nevertheless, the delay bound Δ must be reasonable; otherwise, the light-forest cannot be found to satisfy delay constraint. The Δ is equal to 1.2 times as large as the maximum of transmission delays between the source and all destinations.

In our simulations, we set λ=0.7, γ=0.7, and size of rectangular grid = 100 to simulate the networks with different numbers of nodes consisting of 15% *MC* nodes, where the light splitting capacities of these *MC* nodes are generated randomly. The special net_1 is a network with 100 nodes. Three experiments are simulated on the computer with Intel PIII 850 CPU and 256M RAM to discuss the performance and efficiency of the solution model.

4.1. Comparisons with the *ILP* formulation

The comparisons of multicast costs between experimental results of the *ILP* formulation [9] and the 2-Level procedure are shown in Fig. 1. For the same requests with 4 destinations routing in the networks with different nodes (n=30, 40, …, 100), the solutions found by the 2-Level procedure is near the solutions found by the *ILP* formulation, but the execution times of *ILP* formulation are not affordable. For example, the multicast costs are 176.02 and 183.21, and execution times are 71830 seconds and 8.36 seconds in the network with 100 nodes, respectively. Therefore, the 2-Level may be a good choice to find a near optimal light-tree in less execution time.

4.2. Comparisons between *MaxDepth* and *MaxDest*

The experimental results of execution times and multicast cost distances of different heuristics (*MaxDepth* and *MaxDest*) for different requests are shown in Figs. 2 and 3 for net_1, where x is defined as a value of β divided by α. According to these experimental results in Fig. 2, we observe that the execution times of both are proportional to the numbers of destinations in requests. Moreover, *MaxDest* needs less execution time and increase of execution time is gentler than *MaxDepth*. For some requests, the execution time increase sharply for *MaxDepth*; for example, m=13 and 14. In the Fig. 3, multicast cost distance is the value of subtracting multicast cost by using *MaxDepth* from multicast cost by using *MaxDest*; that is, the multicast cost distance using positive value means that *MaxDepth* can find a light-forest with less multicast cost. According to experimental results, *MaxDepth* may have high probability to find a light-forest with less multicast cost but consume more execution time. For different x with high value, the *MaxDepth* finding a light-forest will have less multicast cost in the case of requests with fewer destinations, but it may not be obviously in the case of request with more destinations.

4.3. Comparisons between *MaxE* and *MinR*

In the experiments, the two heuristics (*MaxE* and *MinR*) are applied to reroute the set of 100 different requests with 5 destinations in the networks with 4 wavelengths and with different numbers of nodes (n=100, 90, and 80). According to the experimental results shown in Table 1, the third and the fourth rows, present the total requests which can be routed successfully and total light-trees in these light-forests found successfully, where these request are named as *success*. The next two rows are used to describe the total communication cost and total multicast cost of success, respectively. The ETS (execution time of success requests), ETF (execution time of failure requests), and total execution time which is a sum of ETS and ETF are described in following. The final row presents the sum of edges of light-trees in success.

In the phase of routing 100 requests, there are about 30% of requests rerouted successfully and the success rates are proportional to the numbers of nodes in network. We can derive that it will need more wavelengths to rerouted more requests concurrently in network with less nodes. Under the condition that partial requests are rerouted, the numbers of light-trees, the communication costs, and the multicast costs of *MaxE* and *MinR* are so ambiguous such that the performances of the two heuristics can't be distinguished. Nevertheless, according to the comparisons between the ETS and the ETF, the *MaxE* needs less execution time to reroute these request successfully than the *MinR*. The ETSs of *MaxE* and *MinR* is proportional to the number of nodes, but the relationship between ETFs and the number of nodes is ambiguous. According to the ratio between ETS and ETF, the *MaxE* seems to be suitable to be applied to the routing problem with more nodes and more concurrent requests to reroute successfully; on the contrary, the *MinR* may be utilized.

5. Conclusion

In this paper, the *MRWA-DC* problem is studied and solved by the 2-*Level* solution model which is an iterative process. Although the discussion of lower bound about the solution found in the solution model is not involved in this paper, experimental simulation can present that the solutions are approximated to the optimal solutions. The *MaxDepth* may have high probability to find a light-forest with less multicast cost but it may consume more execution time. It seems that the *MaxDepth* is suitable to solve the problem with high value of β divided by α in multicast cost object function. In the comparison between *MaxE* and *MinR*, the *MaxE* seems to be suitable to solve the routing problem with more nodes and more concurrent requests to reroute successfully; on the contrary, the *MinR* can be utilized.

Because *WDM* networks with wavelength conversion may route requests more flexibly, the cost of wavelength conversion seem need to be evaluated in multicast cost for finding an efficient light-forest. Nevertheless, for *WDM* networks with sparse wavelength conversion, an extra constraint describing a node with/without wavelength conversion needs to be incorporated. Therefore, the problem becomes more complicated. For further studies, we may seek to refine our solution model to solve the problem, routing a request in the network with sparse wavelength conversion..

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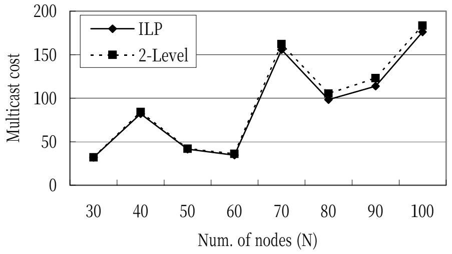

Fig. 1. Comparisons of *ILP* and 2-Level models

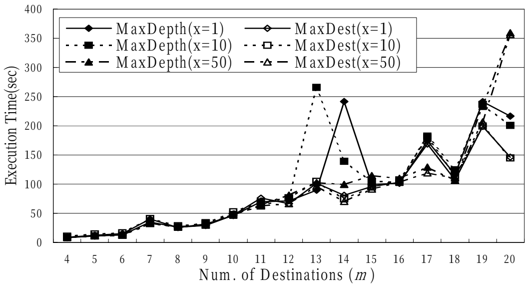

Fig. 2 Comparisons of execution time for different requests

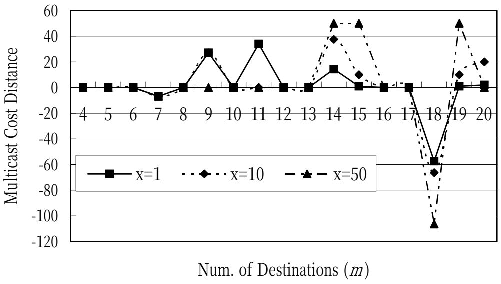

Fig. 3 Comparisons of multicast cost distance for different requests

Table 1. Comparisons of *MaxE* and *MinR*

No. of Nodes	100		90		80	
	MaxE	*MinR*	*MaxE*	*MinR*	*MaxE*	*MinR*
No. of success	31	32	30	29	16	17
Total light-trees	87	91	76	81	46	52
Communication cost	5261.2	5312.6	4106.64	4161.9	2571.0	2635.6
Multicast cost	5348.2	5403.6	4182.6	4242.9	2617.0	2687.6
ETS	4305.2	3669.2	2391.6	2520.5	1005.4	1029.4
ETF	2702.0	4840.7	1997.1	2499.1	2432.2	3554.5
Total execution time	7007.2	8509.9	4388.7	5019.6	3437.7	4584.0