An Integrated QoS Multicast Routing Algorithm Based on Tabu Search in IP/DWDM Optical Internet*

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Abstract. An integrated QoS multicast routing algorithm in IP/DWDM optical Internet is proposed in this paper. Considering load balancing, given a multicast request and flexible QoS requirement, to find a QoS multicast routing tree is NP-hard. Thus, a tabu search based algorithm is introduced to construct a cost suboptimal QoS multicast routing tree, embedding the wavelength assignment procedure based on segment and wavelength graph ideas. Hence, the multicast routing and wavelength assignment is solved integratedly. Simulation results have shown that the proposed algorithm is both feasible and effective.

1 Introduction

In IP/DWDM optical Internet, the integrated QoS (Quality of Service) routing scheme supporting the peer model is necessary [1]. It has been proved NP-hard [2]. In general, most of the existing algorithms aim simply at minimizing the cost of the tree and often only cope with rigid QoS constraints, i.e. the QoS requirements have strict upper or lower bounds [3]. However, due to the difficulty in accurately describing the user QoS requirements and the inaccuracy and dynamics of the network status information, we believe flexible QoS should be supported. This motivates our work. Considering load balancing, given a multicast request and flexible QoS requirement, a tabu search [4] based algorithm is introduced to construct the multicast routing tree, embedding the wavelength assignment procedure based on segment and wavelength graph ideas. Hence, the multicast routing and wavelength assignment is solved integratedly, which could optimize both the network cost and QoS.

2 Model Description

IP/DWDM optical Internet can be considered to be composed of optical nodes (such as wavelength routers or OXCs) interconnected by optical fibers. Assume each optical node exhibits multicast capability, equipped with optical splitter at which an optical

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signal can be split into an arbitrary number of optical signals. In consideration of the still high cost of wavelength converter, assume only some optical nodes are equipped with full-range wavelength converters. Assume the conversion between any two different wavelengths has the same delay. The number of wavelengths that a fiber can support is finite, and it may be different from that of others.

Given a graph $G(V,E)$, where V is the set of nodes representing optical nodes and E is the set of edges representing optical fibers. If wavelength conversion happens at node $v_i \in V$, the conversion delay at v_i is $t(v_i)=t$, otherwise, $t(v_i)=0$. The set of available wavelengths, delay and cost of edge $e_{ij}=(v_i,v_j)\in E$ are denoted by $w(e_{ij})\subseteq w_{ij}=\{\lambda_1,\lambda_2,\cdots,\lambda_{n_{ij}}\}$, $\delta(e_{ij})$ and $c(e_{ij})$ respectively, where w_{ij} is the set of supported wavelengths by e_{ij} and $n_{ij}=|w_{ij}|$.

A multicast request is represented as $R(s,D,\Delta)$, $s\in V$ is the source node, $D=\{d_1,d_2,\cdots,d_m\}\subseteq\{V-\{s\}\}$ is the destination node set, and Δ is the required end-to-end delay interval. Suppose $U=\{s\}\cup D$. The objective is to construct a multicast routing tree from the source to all the destinations, i.e. $T(X,F)$, $X\subseteq V$, $F\subseteq E$.

The total cost of T is defined as follows:

$$Cost(T)=\sum_{e_{ij}\in F} c(e_{ij}) . \tag{1}$$

To balance the network load, those edges with more available wavelengths should be considered with priority. The edge cost function is defined as follows:

$$c(e_{ij})=n-|w(e_{ij})| . \tag{2}$$

$$n=\max_{e_{ij}\in E}\{n_{ij}\} . \tag{3}$$

Let $P(s,d_i)$ denote the path from s to d_i in T. The delay between s and d_i along T, denoted by PD_{sd_i}, can be represented as follows:

$$PD_{sd_i}=\sum_{v_i\in P(s,d_i)} t(v_i)+\sum_{e_{ij}\in P(s,d_i)}\delta(e_{ij}) . \tag{4}$$

The delay of T is defined as follows:

$$Delay(T)=\max\{PD_{sd_i}\mid \forall d_i\in D\} . \tag{5}$$

Let $\Delta=[\Delta_{low},\Delta_{high}]$, and the user QoS satisfaction degree is defined as follows:

$$Degree(QoS)=\begin{cases} 100\% & Delay(T)\le\Delta_{low} \\ \dfrac{\Delta_{high}-Delay(T)}{\Delta_{high}-\Delta_{low}} & \Delta_{low}<Delay(T)<\Delta_{high} \\ 0\% & Delay(T)\ge\Delta_{high} \end{cases} . \tag{6}$$

3 Algorithm Design

3.1 Solution Expression

A solution is denoted by binary coding. Each bit of the binary cluster corresponds to one node in $G(V,E)$. The graph corresponding to the solution S is $G'(V',E')$. Let the function $bit(S,i)$ denote the ith bit of S, $bit(S,k)=1$ iff $v_k \in V'$. The length of the binary cluster is $|V|$. Construct the minimum cost spanning tree $T_i'(X_i',F_i')$ of G'. T_i' spans the given nodes in U. However, G' may be unconnected, thus S corresponds to a minimum cost spanning forest, also denoted by $T_i'(X_i',F_i')$. It's necessary to prune the leaf nodes not in U and their related edges in T_i', the result is denoted by $T_i(X_i,F_i)$, and assign wavelengths to T_i.

3.2 Wavelength Assignment Algorithm

The objective is to minimize the delay of the multicast routing tree by minimizing the number of wavelength conversions, making $Degree(QoS)$ high. If T_i is a tree, assign wavelengths; otherwise, the solution is unfeasible.

(1) Constructing Auxiliary Graph AG

Locate the intermediate nodes with converters in T_i, and divide T_i into segments according to them, i.e., the edges having wavelength continuity constraint should be merged into one segment. Number each segment.

In AG, add node a_0 as the source node, and create node a_j according to segment j, where $j=1,2,\cdots,m$, m is the number of segments. Each node in AG can be considered to be equipped with wavelength converter.

Assume a_k $(1 \le k \le m)$ corresponds to the segment that the source node in T_i belongs to. Add a directed edge (a_0,a_k) between a_0 and a_k, making the intersection of the available wavelength set on each edge in segment k as its available wavelength set. For each node pair a_{j_1} and a_{j_2} $(1 \le j_1, j_2 \le m, j_1 \ne j_2)$, if segments j_1 and j_2 are connected in T_i, add a directed edge (a_{j_1},a_{j_2}) between a_{j_1} and a_{j_2}, making the intersection of the available wavelength set on each edge in segment j_2 as its available wavelength set.

(2) Constructing Wavelength Graph WG

Transform AG to WG. In WG, create $N*w$ nodes, N is the number of nodes in AG, and w is the number of wavelengths available at least on one edge in AG. All the nodes are arranged into a matrix with w rows and N columns. Row i represents a corresponding wavelength and column j represents a node in AG, $i=0,1,\cdots,w-1$ and $j=0,1,\cdots,N-1$. Create edges in WG, where a vertical edge represents a wavelength conversion at a node, assigning 1 as its weight, and a horizontal edge represents an actual edge in AG, assigning 0 as its weight. The construction method is shown in [5].

(3) Wavelength Assignment

Treat WG as an ordinary network topology graph. Find the shortest paths from the source node column to each leaf node column in WG using Dijkstra algorithm, and construct the multicast routing tree T_{WG} . Map T_{WG} back to AG, and denote the resulting subgraph in AG by T_{AG} . Since in WG all the nodes in one column correspond to the same node in AG, those shortest paths that are disjoint in T_{WG} may intersect in T_{AG} . Thus, pruning some edges is needed.

Map the paths in WG back to the paths and wavelengths in AG, and then map them back to the paths and wavelengths in T_i , thus wavelength assignment is completed.

3.3 Generating Initial Solution

A destination-node-initiated joining algorithm [6] is adopted to find an initial feasible solution, leading the algorithm to be more robust with fewer overheads.

3.4 Fitness Function

Fitness function $f(S)$ is determined by $Cost(T_i)$ and $Degree(QoS)$ together:

$$f(S) = \frac{Cost(T_i) + [count(T_i) - 1] * \rho}{Degree(QoS)} . \tag{7}$$

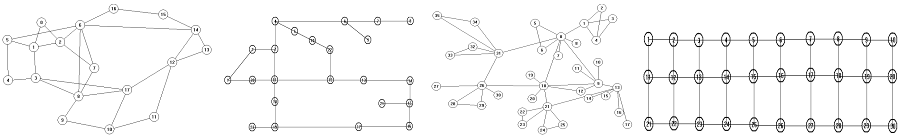
$count(T_i)$ is the number of trees in T_i , ρ is a positive value. If T_i has more than one tree, add a penalty value to the cost of T_i and take a smaller value for $Degree(QoS)$.

3.5 Tabu List

The method of generating neighbors is: choose one node not in *U* randomly, and take the reverse value for the corresponding bit in its solution. Select neighbors randomly to form the candidate set. Tabu object is 0-1 exchange of the components of solution vectors. Tabu length is constant *t*. If a tabued solution in the candidate set could give a better solution than the current optimum one, meaning that a new region has been reached, make it free. Whenever all the solutions in the candidate set are tabued, the object with the shortest tabu term will be freed. If the non-improved iteration times become greater than a given number, clear the tabu list, trying to drive the search into a new region and to get a better solution. Both “stopping after definite iteration times” and “controlling the change of the object value” are adopted as termination rules.

4 Simulation Research

Simulation research has been done over some actual network topologies and mesh topologies with 20 nodes to 100 nodes. Several example topologies are shown in Fig.1.



(a) Topology 1 **(b)** Topology 2 **(c)** Topology 3 **(d)** Topology 4

Fig. 1. Example topologies

4.1 Auxiliary Graph Effect Evaluation

Compare the runtime of the proposed wavelength assignment algorithm (S&WG-based) with that of WG-based [5], the results are shown in Fig. 2. In most cases, the S&WG-based is faster than the other one.

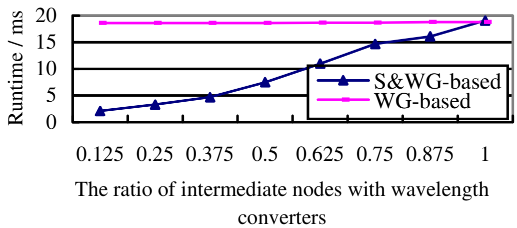


Fig. 2. Evaluation on auxiliary graph effect

4.2 Multicast Routing Tree Cost Evaluation

Comparing solutions obtained by the proposed algorithm with the optimal ones obtained by exhaustive search, the results are shown in Table 1. The solutions obtained by the proposed algorithm are rather satisfied, sometimes are even optimal.

4.3 QoS Evaluation

The delay of the tree obtained by the proposed algorithm and its counterpart obtained without considering $Degree(QoS)$ are compared. Take Topology 1 of Fig. 1 (a) as example, simulation results are shown in Fig. 3. The QoS of the multicast routing tree is improved effectively and efficiently.

Table 1. Evaluation on multicast routing tree cost

Topology	Obtained tree cost vs. optimal tree cost			
	≤ 1%	≤ 5%	≤ 10%	>10%
Topology 1	0.99	0.01		
Topology 2	0.99			0.01
Topology 3	1			
Topology 4	0.78		0.22	

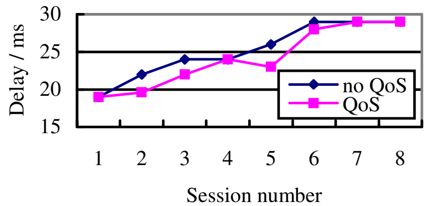


Fig. 3. Evaluation on QoS

5 Conclusions

An integrated algorithm for flexible QoS multicast routing in IP/DWDM optical Internet is proposed. Given a multicast request and flexible QoS requirement, a tabu search based algorithm is introduced to construct QoS multicast routing tree, embedding the wavelength assignment procedure based on segment and wavelength graph ideas. Hence, the multicast routing and wavelength assignment is solved integratedly. Simulation results have shown that the proposed algorithm is feasible and effective.

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