A Tabu Search Optimization for Multicast Provisioning in Mixed-Line-Rate Optical Networks

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Abstract. Mixed-Line-Rate (MLR) optical networks provide the flexibility for satisfying heterogeneous traffic demands. However, the existence of multiple line rates makes the network planning problem more complicated. In this paper, we aim at minimizing the network cost (the joint cost of transponder, wavelength channel usage and the number of used wavelengths) for provisioning multiple multicast sessions simultaneously in MLR optical networks. Two distinct methods are proposed to optimize the network cost: A novel path-based integer linear program (ILP) and a tabu search based heuristic algorithm. Simulation results validate our proposed methods and demonstrate that our tabu search based method is able to compute a near-optimal multicast provision strategy.

Keywords: Optical networks · Mixed Line Rate (MLR) · Multicast provisioning · Tabu search · Integer Linear Programming (ILP) · Light-tree · Lightpath

1 Introduction

In mixed-line-rate optical networks, multiple line rates are available for carrying network traffic with the help of different modulation techniques, for instance 10, 40, and 100 Gbps [1]. As transponder costs and maximum reaches are different for each line rate, using the combination of different line rates for establishing optical communications may help to greatly reduce the network cost. This is why optical networks with mixed line rates are more attractive compared to that of single line rate, especially for satisfying heterogeneous network traffics. All-optical multicasting is an ideal technique for carrying bandwidth-harvest traffic in core networks (e.g. aggregated video traffic or huge data center migration traffic [5]), since it is able to provide a huge bandwidth and achieve the lowest delay [7] by keeping the signal in the optical domain along a light-path or a light-tree [3,10,11]. However, supporting all-optical multicasting is a challenging work in optical networks with mixed line rates. The co-existence of multiple line rates adds a third dimension for network optimization (i.e. line rate selection for each lightpath or a light-tree) in addition to the traditional two dimensions (i.e. routing and wavelength assignment) [9]. Thus, Multicast Routing and Wavelength

Y. Kermarrec (Ed.): EUNICE 2014, LNCS 8846, pp. 14–25, 2014.
DOI: 10.1007/978-3-319-13488-8_2

Assignment with the presence of Mixed Line Rates (MRWA-MLR) becomes a new critical optimization problem for optical network planning.

The multicast routing and wavelength assignment problem for single line rate optical networks has been deeply studied [3,10,11]. Their objective is to find a set of light-trees for satisfying all multicast requests while minimizing the wavelength channel cost or cutting energy consumption. Since these works did not consider the fact that a wavelength can operate at different line rates with different maximum reaches, they can not be reused for solving the MRWA-MLR problem. To the best of our knowledge, [4,9] are the only two papers dealing with the MRWA-MLR problem. Paper [4] proposed a heuristic algorithm to provision static multicast communications in mixed-line-rate Ethernet-Over-WDM networks. As the proposal is only for Ethernet, it is not suitable for WDM core networks. This is because the maximum reach constraint is not considered. Recently, we just propose an ILP model to formulate the MRWA-MLR problem in [9]. However, this model is time consuming and not able to give a solution for networks with up to 11 nodes. Thus, a time-efficient and effective heuristic algorithm is required for provisioning multicast communications with mixed line rates. This motivates our current work.

In this paper, we aim at minimizing the joint network cost while satisfying multiple multicast sessions simultaneously in MLR optical networks. The considered joint network cost involves the transponder cost, wavelength channel usage and the number of used wavelengths. To this end, two distinct methods are proposed: a novel path-based ILP formulation and a tabu search based meta-heuristic algorithm. The proposed new ILP model adopts the concept of using a set of light-paths to form light-trees, while the ILP model [9] constructs directly light-trees. However, both models do not scale with the network size. Thus, a tabu search based method is proposed to optimize the network cost in a reasonable time. Simulation results demonstrate that our tabu search based method is able to compute a near optimal solution for provisioning multicast communications in mixed line rate optical networks. It is also scalable with the network size.

We organize the rest of the paper as follows. The multicast routing and wavelength assignment problem considering multiple line rates is presented in Sect. 2. Then, we propose a novel path-based ILP model to formulate the problem in Sect. 3. A tabu search based meta-heuristic algorithm is proposed to solve the problem for big optical networks in Sect. 4. Simulations are conducted in Sect. 5 to compare the exact solution and the approximated solutions. Finally, the paper is concluded in Sect. 6.

2 Multicast Provisioning in Optical Networks with Mixed Line Rates

All-optical multicasting is an efficient technique for satisfying bandwidth-harvest and delay-critical traffic (e.g. the aggregated traffic of high definition IPTV, or Video conference and etc.). Dimensioning optical networks with multicast traffic is a hard work, especially for optical networks with mixed line rates, what needs to be investigated. In this section, we first give the optical network model and then present the multicast provisioning problem with mixed line rates.

2.1 MLR Optical Network Model

We consider a transparent optical network with mixed line rates. Thus, no regenerator is assumed. We model the studied optical network as a symmetric digraph $G(V, E)$, where V denotes the set of optical cross-connects (OXCs) and E represents the set of links between them. Two links are deployed between two adjacent OXCs with each one for an opposite direction communication. We use d_{uv} to denote the length of a directed link from OXC u to v. All optical links support the same set of wavelengths (noted W) and the same set of line rates (noted R), e.g., $R = \{10, 40, 100\,\text{Gbps}\}$. A transponder working at one line rate $r \in R$ is required to enable a source-to-destination communication in a lightpath or a light-tree. We dispose different line rates, but their maximum reaches are different and so are their costs. The *maximum reach* of a line rate r is denoted by H_r. As reported in [1], the maximum reaches are $H_{10} = 1750\,\text{km}$, $H_{40} = 1800\,\text{km}$ and $H_{100} = 900\,\text{km}$ for line rate 10/40/100 Gbps respectively, when the MLR optical network is dispersion-minimized for 10 Gbps. We should note that higher maximum reach is achieved by 40 Gbps line rate than 10 Gbps in the considered networks [1,8]. In [6], they also define the normalized transponder cost C_r as follows: $\{C_{10} = 1, C_{40} = 2.5, C_{100} = 3.75\}$. Furthermore, we consider huge traffic demand in optical networks. Let S be the set of multicast source OXCs. We assume that multiple multicast communications $\{(s, D_s, B_s) : s \in S, D_s \subset V\}$ arrive at the same time. For a multicast communication originated from source s, D_s is the set of involved destination OXCs, and B_s is the required bandwidth, which is generally bigger than the bandwidth of the highest line rate. Thus a multicast communication may need to use multiple line rates at the same time to satisfy the bandwidth requirement.

2.2 MRWA-MLR Optimization Problem

We study the problem of provisioning multiple multicast sessions simultaneously in optical networks with mixed line rates. Our objective is to minimize the joint network cost, which can be a linear combination of transponder cost for supporting different line rates, the wavelength channel usage, and the number of used wavelengths. The co-efficiency of different costs may be defined the network operator to reduce the real network deployment cost. The advantage of using mixed line rates is that it enables us to satisfy heterogeneous traffic demands efficiently. But, it also increases the network optimization complexity. Thus, when solving the MRWA-MLR problem, one should take into account the following three subproblems:

- (a) Multicast Routing with light-trees or lightpaths.
- (b) Line rate Assignment for light-trees or lightpaths.
- (c) Wavelength Assignment for light-trees or lightpaths

We suppose that light-splitters are available on all OXCs in the network. This enables any OXC to support all-optical multicasting. The wavelength conversion is not considered due to its high cost and hardware complexity. In subproblem (a), several light-trees may be required to satisfy the bandwidth requirement. A light-tree should use the same wavelength and operate at the same line rate over all links. In subproblem (b), the depth of a light-tree, or the length of a lightpath should be bounded to support a certain line rate. Finally, the distinct wavelength constraint (i.e. two light-trees should be allocated with distinct wavelengths unless they are link-disjoint) should be taken into account when solving subproblem (c).

In what follows, two distinct solutions are proposed to solve the MRWA-MLR problem: Path-based ILP formulation and tabu search based meta-heuristic algorithm.

3 A Path-Based ILP Formulation

A light-tree can be viewed as a set of light-paths from the source to each leaf destination who may share a common part with the same wavelength. Based on this concept, we propose a novel path-based ILP formulation in this section, which is different from our previously proposed tree-structure based ILP [9]. We defined four vectors of variables $x^{nd}_{uv\lambda r}$, $h^{nd}_{v\lambda r}$, $y_{uv\lambda}$ and z_λ as follows:

- $x^{sd}_{uv\lambda r} \in \{0,1\}$: Equals 1 if arc (u,v) belongs to the path used between the source node s and the destination node d with the line rate r on wavelength λ.
- $h^{sd}_{v\lambda r} \in [0,M]$: The distance of the path used between the source node s and the destination node d with the line rate r on wavelength λ.
- $y_{uv\lambda} \in \{0,1\}$: Equals 1 if wavelength λ is used on arc (u,v), otherwise 0.
- $z_\lambda \in \{0,1\}$: Equals 1 if wavelength λ is used in the final solution, otherwise 0.

We define V_s as the set of OXCs except the source node, i.e., $V_s = V \setminus \{s\}$. We use $N(v)$ to represent the neighbor OXCs of v in the optical network. For a transponder of line rate r, its cost is noted by c_r. Let C_t be total transponder cost, C_l be the total wavelength channel usage cost, and C_z be the number of used wavelengths, i.e.,
$C_t = \sum_{s\in S}\sum_{d\in D_s}\sum_{\lambda\in W}\sum_{v\in N(s)}\sum_{r\in R} c_r \cdot x^{sd}_{sv\lambda r}$
$C_l = \sum_{(u,v)\in E}\sum_{\lambda\in W} y_{uv\lambda}$
$C_z = \sum_{\lambda\in W} z_\lambda$.
Our objective is to minimize the total joint cost, which can thus be expressed as

$$\min\ \alpha\cdot C_t + \beta\cdot C_l + \gamma\cdot C_z \tag{1}$$

The objective function is subject to the following constraints:

$$\sum_{u \in N(v)} x^{sd}_{uv\lambda r} = \sum_{u \in N(v)} x^{sd}_{vu\lambda r} \quad \forall s \in S, \forall d \in D_s, \forall v \in V - \{s, d\}, \forall \lambda \in W, \forall r \in R \tag{2}$$

$$h^{sd}_{d\lambda r} \leq H_r \cdot \sum_{v \in N(d)} x^{sd}_{vd\lambda r} \quad \forall s \in S, \forall d \in D_s, \forall \lambda \in W, \forall r \in R \tag{3}$$

$$h^{sd}_{v\lambda r} \geq h^{sd}_{u\lambda r} + d_{uv} - M \cdot (1 - x^{sd}_{uv\lambda r}) \quad \forall s \in S, \forall d \in D_s, \forall \lambda \in W, \forall r \in R, \forall (u, v) \in E \tag{4}$$

$$\sum_{r \in R} \sum_{\lambda \in W} \sum_{v \in N(d)} r \cdot x^{sd}_{vd\lambda r} \geq B_s \quad \forall s \in S, \forall d \in D_s \tag{5}$$

$$\sum_{r \in R} x^{sd}_{uv\lambda r} + \sum_{r \in R} x^{s'd'}_{uv\lambda r} \leq y_{uv\lambda} \quad \forall s, s' \in S, s' > s, \forall d \in D_s, \forall d' \in D_{s'}, \forall \lambda \in W, \forall (u, v) \in E \tag{6}$$

$$x^{sd}_{uv\lambda r} + x^{sd'}_{uv\lambda r'} \leq y_{uv\lambda} \quad \forall s \in S, \forall d, d' \in D_s, d' \neq d, \forall r, r' \in R, r' > r, \forall \lambda \in W, \forall (u, v) \in E \tag{7}$$

$$z_\lambda \geq y_{uv\lambda} \quad \forall (u, v) \in E, \forall \lambda \in W \tag{8}$$

$$z_\lambda \geq z_{\lambda+1} \quad \forall \lambda \in W \tag{9}$$

Constraint (2) ensures that for a rate r and a wavelength λ, the number of incoming arcs in a vertex v is equal to the number of outgoing arcs. The constraint (3) makes sure that the length of a path is no bigger than the maximum reach H_r of the line rate chosen for this path. Constraint (4) prohibits cycles and gives a lower height bound to $h^{sd}_{v\lambda r}$. Constraint (5) ensures that traffic received by each destination $d \in D_s$ is at least equal to the traffic required by the multicast session with source s. Constraint (6) prohibits two paths to have the same wavelength if they have a common arc and but start from different sources. Constraint (7) makes sure that two paths starting from the same source can not use the same wavelength if they share a common arc but use different line rates. Constraints (8) and (9) allow us to count the number of used wavelengths and assign them in ascending order.

As we will see in Sect. 5, it is time consuming to compute the optimal solution using this ILP model. Thus, next we present a tabu search based heuristic algorithm for provisioning multicast communications.

4 A Tabu Search Based Multicast Provisioning Algorithm

The tabu search is based on the concepts of neighborhood solution and allowed movements. The neighborhood of a solution is a set of solutions that can be achieved from the first by performing a predefined movement. Each movement is added to a list with fixed size (tabu list) that contains the banned movements. Adequate adaptation of the tabu search metaheuristic is proposed, the general functioning is introduced in Algorithm 1 and its different steps are detailed in the remainder of this section.

Algorithm 1. Tabu search based multicast provisioning

CALCULATION INITIAL SOLUTION

- Generate a set of line rates for each source-destination pair (s, d) of each multicast session. We use the dynamic programming to assure that initial solution satisfy the demand B_s. The selected set of rates represents the modeling of the initial solution.
- Calculate a feasible paths solution corresponding to the selected rates and make the assignment of the wavelengths using a heuristic method.

MOVEMENT SEARCH

- Search the best move (the best switch of line rates) to get the best neighbor solution, except the set of line rates already placed in the tabu list.
- Compute a feasible path solution corresponding to the newly selected line rates and assign wavelengths using a heuristic method (Algorithm 2 introduced later).

UPDATING THE TABU LIST

- Store the newly selected set of line rates in the tabu list.

STOP CONDITION

- Restart the search for a solution until a stop condition is verified (limited movement or computation time).

4.1 Solution Modeling

Any instance of an MRWA-MLR problem is associated with a finite set of feasible solutions; each of which is characterized by a formulation which allows the distinction between different solutions. A solution to the MRWA-MLR problem involves the selection of line rates and the allocation of wavelengths.

Selection of Line Rates. Due to the structure complexity, we consider only the set of selected line rates in the modeling of a solution, the allocation of wavelengths is obtained by a method presented below. Let $Rates_{Sol}$ be the selected line rates for a solution Sol of an instance of the problem, in our tabu search a solution Sol is defined with $Rates_{Sol} = \{Rates_{sd} : \forall s \in S, \forall d \in D_s\}$, where $Rates_{sd} = \{r_1, r_2, ...r_n : r_i \in R, \sum_i r_i \geq B_s\}$ is the set of line rates assigned to each source-destination pair (s, d) that can satisfy the demand B_s and respect the constraints of the maximum transmission reach. More formally, for all $r \in Rates_{sd}$ must exist at least a path between s and d with a length shorter than H_r.

Wavelengths Assignment. Suppose that $Rates_{Sol} = \{Rates_{sd} : \forall s \in Sa, \forall d \in D_s\}$ is the set of selected line rates which define a feasible solution Sol for an instance of the MRWA-MLR problem. We propose a greedy heuristic that is used to calculate the paths of the solution Sol from the selected line rates $Rates_{Sol}$ and make the assignment of the wavelengths. The heuristic proceeds in several iterations, each of which we calculate the best path that could be added to the partial solution.

Before presenting the main contribution of this work, i.e., the wavelengths allocation heuristic algorithm, we introduce the Elementary Shortest Path with Constraints Resources algorithm (ESPPRC) presented in [2]. ESPPRC algorithm permits to calculate the shortest path between a source and a destination under the resource constraint in a network. It will be used several times in our tabu search based multicast provisioning. Let us consider a network $G(V, E, W)$ and the associated arc length d_{uv} for each arc $(u, v) \in E$. In order to calculate the elementary shortest path from a given source $s \in V \cap S$ to one destination $d \in V \cap D_s$ with a given line rate $r \in R$, we adapt the ESPPRC algorithm by considering resources as the total length of the path, which should not be beyond the maximum transmission reach of the selected line rate.

The main idea of the proposed greedy heuristic algorithm is to search in each iteration for the best path that can be added to the partial solution without violating wavelengths allocation constraints. Given a partial solution, we calculate the best path form a given source node s to a given destination node d using a given line rate r on a given wavelength λ using the ESPPRC procedure applied on a graph $G'(V, E, W)$ obtained by deleting from $G(V, E, W)$ each arc (u, v) that satisfies at least one of these three cases:

- The arc (u, v) is crossed by a path p belonging to the partial solution on λ wavelength and the node source of the path p is different from s.
- The arc (u, v) is crossed by a path p belonging to the partial solution on λ wavelength and the line rate used by the path p is different from r.
- The arc (u, v) is crossed by a path p belonging to the partial solution on λ wavelength and the path p provision the session (s, d).

The wavelengths allocation heuristic algorithm is described in Algorithm 2.

4.2 Neighborhood Function

The neighborhood function is an application such that for all Sol associates Sol' if and only if exist at least a session (s, d) such as $Rates_{sd} \neq Rates'_{sd}$ and $Rates_{sd} \in Rates_{Sol}$ and $Rates'_{sd} \in Rates_{Sol'}$. A neighborhood solution Sol' of Sol can be obtained by simple exchange of a line rate $r_i \in Rates_{sd}$ for any session (s, d) but with taking into consideration that the new sets of line rates $Rates'_{sd}$ must satisfy the demand of the session (s, d) and exist at least a path using the line rate r_i that satisfies the constraint of the maximum transmission reach between s and d. It is very clear that the size of the neighborhood depends on the number of sessions and the demand of each session.

4.3 Tabu List

A fundamental element of the tabu search is the use of memory, which is used to keep track of past operations. We can store information relevant to certain stages

Algorithm 2. Wavelengths Allocation Heuristic Algorithm

Data: $G(V, E, W)$ /*The graph modeling the optical network */
$Rates_{sd} = \{r_1, r_2, ...r_n : r_i \in R\}$ /*Set of line rates for each (s, d) */
$Rates_{Sol} = \{Rates_{sd} : \forall s \in S, \forall d \in D_s\}$ /*All used line rates in the solution */
Result: $Paths_{Sol}$ /* A set of paths that constitute the solution. */
initialization;
$Paths_{Sol} \leftarrow \emptyset$;
forall $Rates_{sd} \in Rates_{sol}$ **do**
    forall $r_i \in Rates_{sd}$ **do**
        $AllPaths^{r_i}_{sd} \leftarrow \emptyset$;
        forall $\lambda \in W$ **do**
            /* $G'(V, E, W)$: a graph used in each iteration of the algorithm to model the partial solution. */
            $G'(V, E, W) \leftarrow G(V, E, W)$;
            /* $Cost$:a matrix that contains the costs of arcs in the graph. */
            forall $(u, v) \in W$ **do**
                $Cost[u, v] \leftarrow 1$;
            forall $(s', d', r', \lambda') : Path^{r'\lambda'}_{s'd'} \in Paths_{Sol}$ **do**
                /* affect the cost 0 to each arc already used and remove each arc which can violate the wavelength constraint. */
                forall $(u, v) \in Path^{r'\lambda'}_{s'd'}$ **do**
                    if $\lambda' = \lambda$ **then**
                        $Cost[u, v] \leftarrow 0$;
                    if $s' \neq s$ & $\lambda' = \lambda$ **then**
                        $G'(V, E, W) \leftarrow G'(V, E, W \setminus (u, v))$;
                    if $r' \neq r_i$ & $\lambda' = \lambda$ **then**
                        $G'(V, E, W) \leftarrow G'(V, E, W \setminus (u, v))$;
                    if $s' = s$ & $d' = d$ & $\lambda' = \lambda$ **then**
                        $G'(V, E, W) \leftarrow G'(V, E, W \setminus (u, v))$;
            /* calculate with the ESPPRC procedure, the shortest path from s to d using the line rate r_i, wavelength λ, the graph $G'(V, E, W)$ and the matrix $Cost$. */
            $AllPaths^{r_i}_{sd} \leftarrow$
            $AllPaths^{r_i}_{sd} \cup \{ESPPRC(s, d, r_i, \lambda, G'(V, E, W), Cost)\}$;
        /* chose the path with the minimal cost. */
        $Paths_{Sol} \leftarrow Paths_{Sol} \cup \{\min(AllPaths^{r_i}_{sd})\}$;

of research. This list helps to prevent blockages in the local minima by preventing switching to solution previously visited. The exploration of one neighbor solution is expensive in terms of computation time because of the use of wavelengths allocation heuristic, so in our tabu search method we explore a small number of solutions. This allows us to use a static tabu List which contains all configuration line rates $Rates_{Sol}$ for each solution Sol already visited.

4.4 Initial Solution

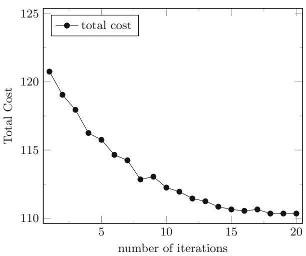
We choose to start the tabu search with a solution that minimizes total transponder cost without taking into account the number of used wavelengths. We resolve the problem of minimizing the cost of line rates for each (s, d) with $s \in S$ and $d \in D_s$. The problem can be formulated as a knapsack problem for each (s, d) where $M_{sd} = \{r_i : \sum_{i,r_i=r} r_i \geq B_s \quad \forall r \in R\}$ is the set of all lines rates that can be selected to salsify the demand B_s, C_{r_i} the cost of the transponder operating at line rate r_i and $x_i^{sd} \in \{0, 1\}$ a decision variable that equals 1 if the line rate $r_i \in M_{sd}$ is used for provisioning (s, d). The objective is to minimize total transponder cost used for each (s, d) pair.

$$\max \sum_{r_i \in M_{sd}} (1 - x_i^{sd}) \cdot C_{r_i} \tag{10}$$

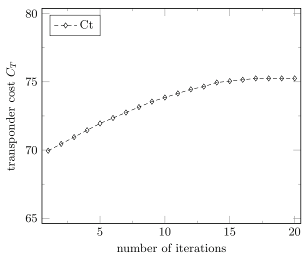
Subject to constraint:

$$\sum_{r_i \in M_{sd}} r_i \cdot (1 - x_i^{sd}) < (\sum_{r_i \in M_{sd}} r_i) - B_s \tag{11}$$

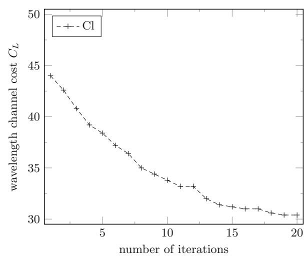
For each (s, d) pair of a multicast session, we resolve the Knapsack with dynamic programming. Once all line rates are selected for each (s, d), we use the



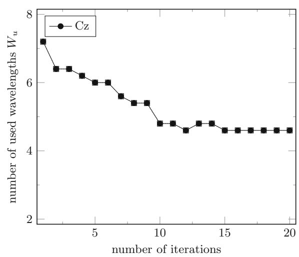
(a) Total Cost vs. number of iterations



(b) transponder cost vs. number of iterations



(c) wavelength channel cost vs. number of iterations



(d) maximum number of used wavelengths vs. number of iterations

Fig. 1. Evolution of costs versus the number of iteration of the tabu search on the 6-node transparent MLR topology [9]

wavelength allocation heuristic algorithm to find the set of lightpaths and assign the wavelengths for the initial solution.

5 Simulation and Numerical Results

We evaluate our tabu Search based multicast provisioning heuristic algorithm on three different topologies: 6-node sample network [9], the cost-239 network (11 nodes and 52 directed links) [1], and European Optical Network (EON, 28 nodes and 88 directed links) [8]. Simulations were conducted using IBM ILOG CPLEX version 12.5 on an Intel Core PC equipped with a 3.3 GHz CPU and 4G Bytes RAM. The Total Cost in the set of tests is given by the objective function (Eq. (1)), where the coefficients α, β and γ are equal to 1 but our algorithm is valid for any coefficients. To validate the proposed tabu search based heuristic algorithm, we consider two metrics: the convergence speed (the number of iterations for convergence) and the gap to the optimal solution.

Figure 1 presents the evolution of different costs for the 6-node optical network versus the number of iteration of the proposed tabu search based heuristic algorithm. We can observe at the end of 15 iterations, our approach is about to obtain the best total cost. It is shown that our approach starts with the best possible transponder cost by using dynamic programming. The tabu search tries

Table 1. Simulation Results

Instances				MILP model			Tabu search				
Name	Session	$\lvert D_S \rvert$	B_S	Total cost	Gap (%)	Time (s)	Total cost	Ct	Cl	Cz	Time
6-MLR	2	3	120	53.5	0	9.55	54.5	37.5	14	3	40.793
	3	3	120	80.5	0	2163.8	81.25	56.25	22	3	80.852
	4	3	120	107	11.43	9760	110	75	30	5	124.437
	5	3	120	132.75	14.2	11048.5	135.75	92.75	37	6	198.594
	6	3	120	164.75	15.3	10126.3	167.75	113.75	48	6	261.866
Cost-239 MLR	2	3	100	58.5	40.93	6910.03	58.5	37.5	18	3	26.292
	4	3	100	–	–	7200	104.5	67.5	33	4	53.396
	6	3	100	–	–	7200	158.25	101.25	53	4	146.245
	8	3	100	–	–	7200	221.75	138.75	76	7	362.446
	10	3	100	–	–	7200	279.5	172.5	100	7	802.142
Cost-239 MLR	2	5	300	–	–	7200	216.5	147.5	61	8	32.879
	4	5	300	–	–	7200	428.25	286.25	129	13	133.931
	6	5	300	–	–	7200	656.75	432.75	211	13	638.075
	8	5	300	–	–	7200	930.5	607.5	299	24	4157.52
	10	5	300	–	–	7200	1180.75	761.75	396	23	3868.7
28 EON	2	5	300	–	–	7200	309.5	182.5	112	15	231.889
	4	5	300	–	–	7200	589.5	332.5	235	22	803.447
	6	5	300	–	–	7200	859.25	501.25	336	22	2604.55
	8	5	300	–	–	7200	1221.75	673.75	523	25	2938.78
	10	5	300	–	–	7200	1397.5	794.5	579	24	4287.12

to decrease the wavelength channel cost and the number of used wavelengths progressively in each iteration so that the total cost can be improved. In other words, the tabu search deteriorates the transponder cost to cut down the used wavelengths and the wavelength channel usage. We can observe also that total cost is reduced by 8.28 % on average.

Table 1 summarizes our empirical results for the aforementioned three topologies. As we find that computation time mainly depends on the network size, the number of sessions, the number of destinations of a multicast session, and the traffic demand, we report test results mainly based on these factors. We can see that the ILP is still too time-consuming to compute the optimal solution in median and big optical networks. Our tabu search based algorithm obtains almost the same results as the optimal solution computed by the ILP model (with a gap of 1.84 % on average) in the 6-node optical network. The tabu search method also permits to get approximated solutions for big instances in Cost-239 network and 28-node EON in a reasonable time while the ILP based counterpart can not. Thus, we can say our tabu search based heuristic algorithm is able to find the near-optimal solution and it is scalable for large networks.

6 Conclusion

An efficient tabu search based heuristic algorithm is proposed to provision multiple multicast communications in Mixed-Line-Rate optical networks. Our objective is to minimize the joint network cost. In our approach, we use dynamic programming to find the suitable set of line rates, and use a new wavelength allocation heuristic to solve the lightpath computation and wavelength assignment. For comparison, a path-based ILP formulation is also proposed to search the optimal solution for small networks. Simulation results confirm that our proposed tabu search based algorithm allows to get a near-optimal strategy for multicast provision, and this method is scalable for large optical networks with mixed line rates.

Acknowledgments. This work is supported by the internal grant of the Computer Science Lab (LIA), University of Avignon, France and the open project (2013GZKF031 309) of the State Key Laboratory of Advanced Optical Communication Systems and Networks, Shanghai Jiao Tong University, China. The authors would like to thank Dr. Boris Detienne (IMB, University of Bordeaux 1) for his valuable discussions and suggestions.

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Advances in Communication Networking
20th EUNICE/IFIP EG 6.2, 6.6 International Workshop,
Rennes, France, September 1-5, 2014, Revised Selected
Papers
Kermarrec, Y. (Ed.)
2014, X, 227 p. 76 illus., Softcover
ISBN: 978-3-319-13487-1