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Joint Capacity Allocation in Multi-layer Survivable Networks*

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Abstract A joint capacity allocation approach is proposed to optimize spare capacity in multi-layer survivable networks. Depending on a full overview of all network layers, the joint capacity allocation approach can realize the maximum sharing of spare capacity among layers. The spare capacity allocation problem in multi-layer survivable networks is formulated through Integer Linear Programming, while for large-scale networks, a genetic algorithm is also proposed for possible optimal solution. Numerical results illustrate that the proposed approach is much more cost-effective. Due to the introduction of coordination among different layers, the proposed approach can also avoid the backhauling problem.

Keywords Multi-layer Networks; Spare Capacity Sharing; Survivability; ILP; Genetic Algorithm
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0 引言

In order to manage service and facility conveniently and utilize transmission facilities efficiently, the operation of the modern telecommunication network is based on a multi-layer architecture. The most common example of multi-layer telecommunication network is the ATM over SDH over WDM configuration[1,2]. Because the life span of telecommunication network equipment is usually several decades, the removal of legacy systems is an expensive waste for the operators. Therefore, they are willing to preserve their network equipment for quite a long time. The operators are running their IP network in parallel with their currently existing network services, on top of the same transport network. This means they typically are in an IP/ATM/SDH/WDM multi-layer scenario. Therefore, optimum network design in such multi-layer network can not only improve network survivability, but also help the operators to increase their revenues coming from data traffic.

The ACTS project PANEL[3] investigated the interworking of multi-layer recovery mechanisms, and a multi-layer recovery framework was defined and published in[4]. The multi-layer recovery framework considers the recovery mechanisms present in single-layer, the planning of spare resources in multi-layer, the multi-layer recovery strategy and interworking mechanisms. A sequential strategy was proposed to dimension spare capacity, which is called as sequential capacity allocation (SCA) here. In this spare capacity allocation strategy, top-down and bottom-up approaches were used, and each layer's restoration routes are determined independently[5], so capacity sharing can only achieved in the same layer. For example, in SDH layer, the restoration capacity reserved for ATM layer demands cannot be shared with the restoration capacity reserved for SDH layer native demands. SCA produces unnecessary extra spare capacity in lower layer due to separate dimensioning processes[6]. In this paper, a joint capacity allocation (JCA) approach is presented. Unlike the sequential capacity allocation (SCA) approach, JCA can map the upper layer into the lower layer smartly, which can allow sharing of spare capacity from both the same level restoration routes and different level restoration routes. That is, in JCA, each layer's restoration routes are determined simultaneously considering maximum sharing among restoration routes in SDH and WDM layers. Moreover, due to the introduction of coordination among different layers, JCA can also avoid the backhauling problem. In this paper, JCA and SCA are formulated as Integer Linear Programming tasks. The problem being computationally intractable for large-scale multi-layer networks, a genetic algorithm approach is also proposed to optimization. In addition, JCA is compared with SCA to see how much spare capacity can be reduced, and numerical results illustrate that JCA is much more cost-effective SCA.

1 Spare capacity allocation in multi-layer survivable networks

1.1 Problem definition

Assumed that the traffic demands are known in advance. They may correspond to a long-term traffic forecast. Initial ATM, SDH and WDM topologies are given in advance, and all spans in the topologies are assumed to be bidirectional. For routing a demand, 3 possible routes are considered. The shortest route is selected as working path, and another two shortest routes

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are selected as restoration paths. The two restoration paths must be node disjoint with the working path in the same layer, but not necessary with each other. The goal of optimization is to select the best one from the two restoration routes, with according dimensioning, in order to end up with the least network cost.

In sequential capacity allocation (SCA) approach, the higher layer lacks the awareness of the exact capacity and topology information from the lower layer. SCA can only share spare capacity from the same level restoration routes. In this paper, top-down approach is used as shown in Fig. 1(a). ATM layer's spare capacity is optimized based on ATM demands. SDH layer's spare capacity is optimized based on SDH layer native demands and the demands from ATM layer. WDM layer's spare capacity is optimized based on WDM layer native demands and the demands from SDH layer. In SCA, three shortest paths have been found by traditional k-shortest paths algorithm. Because only one layer topology is considered, they may be the 3-shortest paths in the higher layer, but not in the lower layers. Worse of all, in SCA, a restoration route selected in a higher layer may have backhauling problem in the lower layer due to the missing of mapping information among layers.

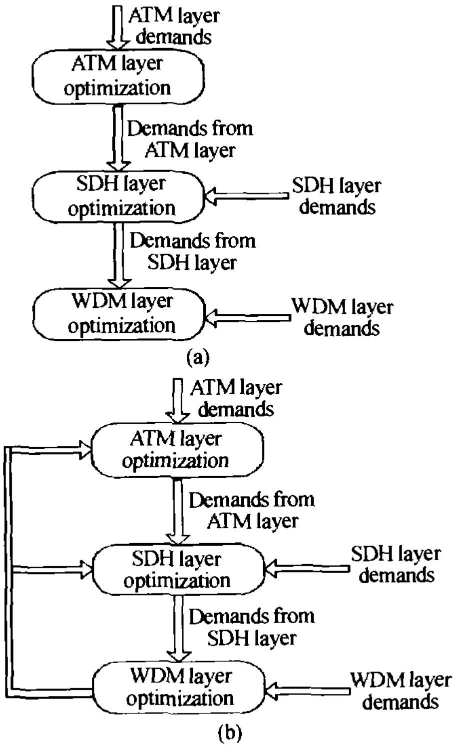


Fig. 1 The sketch map of (a) Sequential capacity allocation approach and (b) joint capacity allocation approach

In joint capacity allocation approach (JCA), depending on a full overview of all network layers, it's possible to share spare capacity from both the same level restoration routes and different level restoration routes. Three layers optimization is run jointly so that the total spare capacity can be reduced as shown in Fig. 1(b). In JCA, three shortest paths have been found by a modified k-shortest paths algorithm, which considers all layer topologies. Therefore, the total costs of the paths are real 3-shortest in the multi-layer network, and the backhauling problem can be avoided.

The network optimization problem is formulated as an Integer Linear Programming (ILP) task. ILP has to be used instead of LP to avoid flow branching. To solve this problem, some available package (e. g. LP_SOLVE or CPLEX[7]) can be used. The ILP models of SCA and JCA are presented in the next section.

Indices:

A, S and W used as subscripts, denote the ATM, SDH and WDM layer

i, j and k used as subscripts, denote the ATM, SDH and WDM layer demands

x, x_1 and x_2 used as subscripts, denote the ATM, SDH, and WDM layer candidate restoration paths for ATM layer demands

y and y_1 used as subscripts, denote the SDH and WDM layer candidate restoration paths for SDH layer demands

z used as subscripts, denote the WDM layer candidate restoration paths

Problem parameters:

O_A, O_S and O_W The set of demand pairs in ATM, SDH, and WDM layer

L_A, L_S and L_W The set of network spans in ATM, SDH and WDM layer

d_i, d_j and d_k Number of demand units (for instance, the demand unit in ATM, SDH and WDM layer is OC-3, OC-48 and OC-192, respectively) of demand i, j and k in ATM, SDH and WDM layer

C_A^l, C^l, C_S, C_W^l Cost of adding a unit capacity to span l in ATM, SDH and WDM layer

F_A, F_S and F_W Cost proportion factor of demand unit among layers

X The set of candidate restoration paths for ATM layer demands

X_1 The set of candidate restoration paths for ATM layer demands mapping in SDH layer

X_2 The set of candidate restoration paths for ATM layer demands mapping in WDM layer

Y The set of candidate restoration paths for SDH layer demands

Y_1 The set of candidate restoration paths for SDH layer demands mapping in WDM layer

Z The set of candidate restoration paths for WDM layer demand pairs

R_{AS} Rate proportion factor between ATM and SDH layer

R_{SW} Rate proportion factor between SDH and WDM layer

$\gamma_{x,l}^i$ If restoration path x for traffic demand i passes over ATM span 1, then the value is l, otherwise 0

$\gamma^{i}_{x_1,l}$　If restoration path x_1 for traffic demand i passes over SDH span l, then the value is 1, otherwise 0

$\gamma^{i}_{x_2,l}$　If restoration path x_2 for traffic demand i passes over WDM span l, then the value is 1, otherwise 0

$\gamma^{j}_{y,l}$　If restoration path y for traffic demand j passes over SDH span l, then the value is 1, otherwise 0

$\gamma^{j}_{y_1,l}$　If restoration path y_1 for traffic demand j passes over SDH span l, then the value is 1, otherwise 0

$\gamma^{k}_{z,l}$　If restoration path z for traffic demand k passes over WDM span l, then the value is 1, otherwise 0

Variables:

$\delta^{i}_{x}, \delta^{j}_{y}, \delta^{k}_{z}$　Variable shows which restoration path is selected for demand i, j and k in ATM, SDH and WDM layer, respectively

Computed values:

$n^{l}_{A}, n^{l}_{S}, n^{l}_{W}$　Number of demand units on span l in ATM, SDH and WDM layer, respectively

1.2 JCA ILP model

In JCA, the total cost in ATM, SDH and WDM layer is minimized jointly. The ILP formulation is as follows:

Objective:

Minimize

$$[F_A \sum_{l \in L_A} C^{l}_{A} n^{l}_{A} + F_S \sum_{l \in L_S} C^{l}_{S} n^{l}_{S} + F_W \sum_{l \in L_W} C^{l}_{W} n^{l}_{W}] \tag{1}$$

The objective function minimizes the total cost of ATM, SDH and WDM layer. Three terms in the function represent ATM layer cost, SDH layer cost, and WDM layer cost, respectively.

Constraints on ATM layer survivability

$$n^{l}_{A} \geqslant \gamma^{i}_{x,l} \delta^{i}_{x} d_i$$
$$\forall x \in X, \forall l \in L_A, \forall i \in O_A \tag{2}$$

Equation (2) ensures that the bandwidth on restoration span l in ATM layer is large enough to recover any ATM traffic demand whose restoration path passes over span l.

Constraints on SDH layer survivability:

$$n^{l}_{S} \geqslant R_{AS} \gamma^{i}_{x_1,l} \delta^{i}_{x} d_i$$
$$\forall x1 \in X_1, \forall l \in L_S, \forall i \in O_A \tag{3}$$
$$n^{l}_{S} \geqslant \gamma^{j}_{y,l} \delta^{j}_{y} d_j$$
$$\forall y \in Y, \forall l \in L_S, \forall j \in O_S \tag{4}$$

Equation (3) and (4) ensure that the bandwidth on restoration span l in SDH layer is large enough to recover any ATM traffic demand and SDH traffic demand, whose restoration path passes over span l.

Constraints on WDM layer survivability

$$n^{l}_{W} \geqslant R_{AS} R_{SW} \gamma^{i}_{x_2,l} \delta^{i}_{x} d_i$$
$$\forall x_2 \in X_2, \forall l \in L_W, \forall i \in O_A \tag{5}$$
$$n^{l}_{W} \geqslant R_{SW} \gamma^{j}_{y_1,l} \delta^{j}_{y} d_j$$
$$\forall y_1 \in Y_1, \forall l \in L_W, \forall J \in O_S \tag{6}$$
$$n^{l}_{W} \geqslant \gamma^{k}_{z,l} \delta^{k}_{z} d_k$$
$$\forall z \in Z, \forall l \in L_W, \forall k \in O_W \tag{7}$$

Equation (5), (6) and (7) ensure that the bandwidth on restoration span l in WDM layer is large enough to recover any ATM traffic demand, SDH traffic demand and WDM traffic demand, whose restoration path passes over span l.

The constraints to ensure that there is no traffic split for restoration is

$$\sum_{x \in X} \delta^{i}_{x} = 1 \quad \forall i \in O_A \tag{8}$$
$$\sum_{y \in Y} \delta^{j}_{y} = 1 \quad \forall j \in O_S \tag{9}$$
$$\sum_{z \in Z} \delta^{k}_{z} = 1 \quad \forall k \in O_W \tag{10}$$

1.3 SCA ILP model

In SCA, the whole optimization process is divided into three steps. In the first step, ATM layer's spare capacity is optimized based on ATM demands. In the second step, SDH layer's spare capacity is optimized based on SDH layer native demands and the demands from ATM layer. In the last step, WDM layer's spare capacity is optimized based on WDM layer native demands and the demands from SDH layer. The ILP formulation is as followings:

1) Step 1: ATM layer optimization:

Objective:

$$\text{Minimize} \quad F_A \sum C^{l}_{A} n^{l}_{A} \tag{11}$$

Constraints on ATM layer survivability: Same as (2).

No traffic split for restoration constraints: Same as (8).

The value of variable δ^{i}_{x} is known after this step, which will be used for next steps.

2) Step 2: SDH layer optimization:

Objective:

$$\text{Minimize} \quad F_S \sum C^{l}_{S} n^{l}_{S} \tag{12}$$

Constraints on SDH layer survivability: Same as (3) (4).

No traffic split for restoration constraints: Same as (9).

The value of variable is known after this step, which will be used for the next step.

3) Step 3: WDM layer optimization:

Objective:

$$\text{Minimize} \quad F_W \sum C^{l}_{W} n^{l}_{W} \tag{13}$$

Constraints on WDM layer survivability: Same as (5) (6) (7).

No traffic split for restoration constraints: Same as (10).

1.4 Genetic algorithm

Each working route may have several candidate restoration routes. One of them will be selected for the working path in time of working path failure. The joint capacity allocation is to assign restoration paths and spare capacity along selected paths for all working paths in all layers while maximizing sharing of spare capacity among restoration paths. The problem being computationally intractable for large-scale multi-layer networks, a genetic algorithm approach is proposed to optimization.

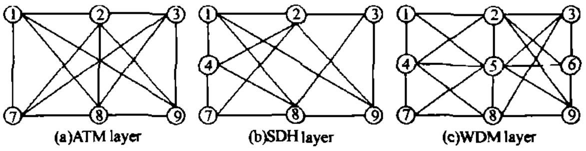
The Genetic Algorithm (GA)[8-10] is a general optimization technique which mimics the genetic evolution of species. The main difference with other A.I. approaches, as for instance Simulated Annealing or Tabu Search, is that GA deals with a 'population' of solutions (a solution is called a 'chromosome') rather than with a single solution. A solution consists of a set of variables. Each variable can have a value taken from a domain. In this paper, the solution is a set of binary numbers. The value of the variable corresponds to which candidate path is selected as restoration path. Since GA tries to emulate nature, at any discrete time, T, the current population is referred to as the T^{th} generation. By moving from one generation to another, the quality of the population is improved. The combination of the crossover and mutation helps GA to escape from getting mired in local optima. These properties of GA provide a good global search methodology for the spare capacity allocation in multi-layer networks. The process is terminated if the number of iterations exceeds a specific value or the population converges.

2 Simulation and numerical results

In this paper, a small network and the NSFNET-like network are used for comparing JCA with SCA to see how much network cost is reduced. Assumed that the data transfer rates in ATM, SDH and WDM layer are 155 Mbit/s, 2.5 Gbit/s and 10Gbit/s respectively. Therefore, the rate proportion factor R_{AS} and R_{SW} are 1/16 and 1/4 respectively. The cost of each span is 1. In addition, $F_A=1$, $F_S=5$, and $F_W=2$.

2.1 Small network using integer linear programming

In this section, a 9-node network is used for comparing JCA with SCA as shown in Fig. 2. Due to different service granularity and node placement, different layer has a different topology. Because there isn't an ATM digital cross-connect (DXC) at a node position 4, ATM layer topology is different from SDH layer topology. SDH layer topology is also different from WDM layer topology due to no SDH DXC at node position 5 and 6.



(a)ATM layer (b)SDH layer (c)WDM layer

Fig. 2 Three layer topologies of the small network

In this paper, there are 10 traffic demands for different node pairs in ATM, SDH and WDM layer respectively. The values of traffic demands are randomly generated.

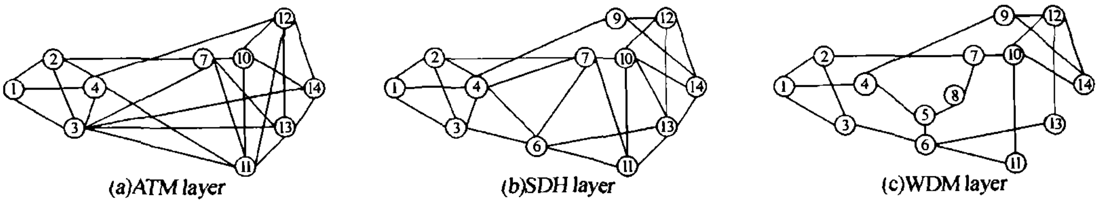
The results of spare capacity cost comparison between JCA and SCA are shown in table 1. The network costs of each layer and all layers using SCA and JCA approach are shown in the second column and the third column respectively. The total cost reduction is 8.3%, which means that JCA is more cost-effective than SCA. The cost reduction in ATM layer is a negative value of -3.3%. The reason of larger ATM layer cost in JCA is that a longer restoration route in ATM layer may make more sharing in SDH and WDM layer.

Table 1 Spare capacity cost comparison between SCA and JCA

	SCA	JCA	Cost Reduction %
ATM Layer Cost	501	518	-3.3%
SDH Layer Cost	645	585	10.3%
WDM Layer Cost	980	860	13.9%
Total Cost	2126	1963	8.3%

2.2 Large scale network using genetic algorithm

In this section, the NSFNET-like network is used for comparing JCA with SCA as shown in Fig. 3. There are 22, 23 and 24 traffic demands for different node pairs in ATM, SDH and WDM layer respectively. The values of these traffic demands are also randomly generated.



(a)ATM layer (b)SDH layer (c)WDM layer

Fig. 3 Three layer topologies of NSFNET

The genetic algorithm is used for JCA, and ILP method is used for SCA. Because the number of generation is incremented, more computation time is required. In this paper, the maximum generation is 10000; the initial population is 50; the crossover rate is 0.6; and the mutation rate is 0.3.

The results of spare capacity cost comparison

Table 2 Spare capacity cost comparison between SCA and JCA

	SCA	JCA	Cost Reduction %
ATM Layer Cost	1272	1355	-6.1%
SDH Layer Cost	3200	2770	15.5%
WDM Layer Cost	3110	2620	14.3%
Total Cost	7582	6745	12.4%

between JCA and SCA are shown in table 2. The total cost reduction is 12.4%, which means that JCA is much more cost effective than SCA.

2.3 Backhauling problem

As mentioned in Section 1, SCA may have backhauling problem due to the missing of mapping information among layers, but JCA will not. For instance, Assumed that there is an ATM traffic demand between node 7 and node 10 in Fig. 3. The mapping routes in three layers are presented in Table 3.

Table 3 An example of mapping information of routes in three layers

	working path	restoration path - 1	restoration path - 2	restoration path - 3
ATM layer	7-10	7-11-10	7-3-11-10	7-13-11-10
SDH layer	7-10	7-11-10	7-2-3-6-11-10	7-6-13-11-10
WDM layer	7-10	7-8-5-6-11-10	7-2-3-6-11-10	7-8-5-6-13 06-11-10

In SCA, 7-13-11-10 may be selected as a restoration path for working path 7-10, which has a backhaul span 6-13-6 in WDM layer as shown in Table 3. However, it will be avoided in JCA depending on a full overview of all network layers.

3 Conclusions

Minimizing the capacity allocated to restoration routes will be able to accept and serve further traffic demands. In this paper, the spare capacity allocation problem is investigated in multi-layer survivable networks. A joint capacity allocation (JCA) approach is proposed. The Integer Linear Program (ILP) models of joint capacity allocation approach and sequential capacity allocation (SCA) approach are formulated. The genetic algorithm is used to optimize spare capacity allocation in large-scale multi-layer networks. Numerical results show that JCA is much more cost-effective than SCA. Due to the coordination among different layers, JCA can also avoid the backhauling problem. Moreover, JCA can be extended for two layers scenario, such as IP over WDM.

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多层网络中的联合资源配置方案

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摘　要　在多层网络的资源配置中,为了实现备份资源在各网络层的最大共享,在综合考虑网络各层的资源使用信息和拓扑信息的基础上,提出了一种联合的资源配置方案.在建立资源分配方案的整数线性规划模型的同时,提出了适合解决大规模网络的遗传算法.数值结果表明:联合资源配置方案可以更好地共享各网络层的备份资源,从而使多层网络具有更高的带宽利用率和更低的运营成本.由于引入了各网络层的协调,从而防止了回路问题.

关键词　多层网络;备份资源共享;生存性;整数线性规划;遗传算法

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