Combining Node and Link Dimensioning for MPLS Networks

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Abstract

This paper presents a procedure for Multi-Protocol Label Switching (MPLS) network dimensioning that deals with both the determination of the transmission facilities to be put in operation between routing sites and the determination of routing equipment that must be installed in each routing site. The dimensioning procedure aims to find the least cost physical network. The proposed approach considers two types of costs: O&M (operation and maintenance) costs and upgrade costs. The lifetime of an operator's network is seen as being composed by consecutive cycles, where the network must be dimensioned for the traffic forecast of the next cycle. In each dimensioning step, the operator has two objectives. First, it wants to minimise the O&M cost of the required network and second, it wants to minimise the cost of the required node equipment upgrade. This approach results in two steps, each one given by an optimisation problem. The first problem determines the transmission facilities required between network nodes. The second problem determines the routing equipment that must be installed in each node. In the second step problem, upgrade costs include the acquisition costs of buying new equipment, transfer costs of moving existing equipment from one node to another, and storage costs when equipment that is in operation in the present cycle is not used in the next cycle.

1 Introduction

IP networks are currently evolving from their original architecture, capable of supporting a single Best Effort class of service, towards a new advanced architecture characterised by the capability of supporting different classes of services. This evolution enables the utilisation of IP networks to offer a wide variety of highly valuable services, creating new business opportunities for Telecom Operators and accelerating the process of renewing their network infrastructure.

To be successful, however, this process requires a greater capability of managing network resources. As a consequence, there is an increasing interest towards the definition and the implementation of techniques that can meet the desired level of resource management under different operational conditions. This field of activity is usually referred to as Traffic Engineering (TE), which is made possible for IP networks through Multi-Protocol Label Switching (MPLS) technology [1].

MPLS is an advanced forwarding scheme for IP networks supporting Quality of Service (QoS). A router that supports MPLS is known as a Label Switching Router (LSR). MPLS organises the network in MPLS domains. In an MPLS domain, client traffic is submitted to Ingress LSRs, then forwarded through LSRs up to the appropriate Egress LSR and, finally, delivered to the destination client equipment. The forwarding of IP packets from Ingress to Egress LSRs is done by means of routing paths, called Label Switched Paths (LSPs). In the Ingress LSR, incoming IP packets are classified based on the required QoS, and depending on this classification, are forwarded through the appropriate LSP.

IP TE has been defined as "that aspect of Internet network engineering that deals with the performance evaluation and performance optimisation of operational IP networks" [2]. Therefore, IP TE influences several network engineering aspects. Basically, the TE problem is an optimisation problem [1] having a non real-time component and a real time component. The non real-time component is part of the network planning and dimensioning process, and has the objective of optimising the network with respect to the nominal expected traffic, taking into account the operator requirements in terms of QoS to be provided and network reliability and resilience. The real-time component, on the other hand, is part of the network management and control process and has the objective of adapting the network in response to traffic variation or equipment faults so that QoS objectives can still be met. This paper focuses on TE aspects related to the network planning and dimensioning phase.

This paper presents a procedure for MPLS network dimensioning that deals with both the determination of the transmission facilities to be put in operation between routing sites and the determination of routing equipment that must be installed in each routing site. The lifetime of an operator's network is seen as being composed by consecutive cycles. At the end of each cycle, the network is to be re-dimensioned for the traffic forecast of the next cycle. The proposed network dimensioning procedure considers two types of costs:

(i) O&M (operation and maintenance) costs. These costs are modelled by a cost value for each transmission facility type between each pair of routing sites and is given by 2 × (routing cost) + (transmission cost) × (distance between routing sites). The routing cost is the average O&M cost of the equipment capable of routing the capacity of the transmission facility. The transmission cost is the average O&M cost of the transmission system per unit of distance.

(ii) Upgrade costs. This type of costs is associated with the installation, at the beginning of a new dimensioning cycle, of the appropriate routing equipment. These costs include the acquisition costs (equipment that must be bought), the transfer costs (equipment that must be transferred from one site to another site) and the storage costs (equipment that is no longer necessary for the next cycle and is stored for future needs).

Note that these two types of costs are different in nature. O&M costs are usually on a per month basis, while investment costs must be covered only at the beginning of the cycle. In the present approach, we consider that O&M costs are dominant and, therefore, the joint link and node dimensioning aims, in a first step, to minimise the O&M network cost and, in a second step, minimise the upgrade cost. This approach results in two steps, each one given by an optimisation problem. The solution of the first problem determines the transmission facilities required between routing sites. The solution of the second problem determines the routing equipment that must be installed in each routing site.

The remaining of the paper is organised as follows. In section 2 we present the combined node and link network dimensioning procedure. In section 3 we discuss its usefulness and performance through a case study. Finally, section 4 presents the main conclusions.

2 MPLS Network Dimensioning

The dimensioning of the network is performed in two steps. In the first step, an algorithm that performs multi-hour network dimensioning and considers mixed peer-to-peer and client-server services is used to determine the transmission facilities required between routing sites. In the second step, a branch-and-bound algorithm is used to determine the equipment configuration of each node. Each dimensioning problem is described in the following two subsections.

2.1 Link Dimensioning Problem

The link dimensioning procedure performs multi-hour network dimensioning and considers mixed peer-to-peer and client-server services.

For each client-server service, there are client nodes (which are Ingress/Egress nodes) and server nodes. The dimensioning procedure determines, for each client-server service and each Ingress/Egress node, a LSP route between the Ingress/Egress node and one of the server nodes. Each LSP is defined by an origin node, a set of pre-defined candidate server nodes, maximum bandwidth and, if defined, a set of selectable routes.

For each peer-to-peer service, the dimensioning procedure determines, for each service, one LSP route between each pair of Ingress/Egress nodes of the service. Each LSP is defined by an origin node, destination node, maximum bandwidth and, if defined, a set of selectable routes, a set of usable colours, a maximum number of hops and a survivability option.

Link attributes must also be defined: maximum utilisation (a value between 0% and 100%) and colour.

The attributes defined for each LSP impose constraints that must be satisfied in the dimensioning solution. The selectable routes attribute, if defined, is a set of routes from which the LSP path must be selected. The usable colours attribute can be defined to forbid a link to be used by a certain LSP, e.g., an LSP with the set {yellow, green} cannot use links of any other colour (by default, all LSPs can use all links). Maximum hop count attribute can be used to limit the maximum number of LSRs crossed for a particular LSP. The survivability attribute is defined by its type and degree. The survivability types are link disjoint and node disjoint and the degree is a value between 50% and 100%. When this attribute is set for a particular LSP, the procedure splits the LSP in two, giving each one a bandwidth between 50% and 100% (given by the degree) of the original LSP. When node disjoint is considered, the two routes of the LSPs must be node disjoint along the entire path between origin and destination. When link disjoint is considered, the two routes of the LSPs must be link disjoint, but in this case they can have common nodes.

This problem is formulated as an integer programming problem, which is solved through an heuristic based on Lagrangean relaxation with sub-gradient optimisation that has been previously proposed for ATM [3-5] and for MPLS networks [6-7].

The detailed of the link dimensioning procedure can be found in [6].

2.2 Node Dimensioning Problem

Node dimensioning procedure configures each network node aiming to minimise the overall upgrade cost.

This problem has the following input parameters: (i) number of transmission facilities of each type ending in each routing site (given by the previous link dimensioning procedure), (ii) the set of available router models and network cards that can be acquired and (iii) the number and location of routers of each type and number and location of network cards of each type that are presently installed in each routing site. This problem determines the routing equipment that must be set-up in each node. The optimisation function is the sum of acquisition costs (when equipment must be bought), transfer costs (when existing equipment must be transferred from one node to another), and storage costs (when equipment that was in operation is no longer useful and must be stored).

Network routers are characterised by the number of slots. Network cards are characterised by the type and number of transmission interfaces. Any network card can be plugged in any router slot. The proposed procedure is valid for networks with a single equipment provider.

This problem is formulated as an integer linear programming problem. Consider the following input parameters to the problem:

- N set of routing nodes plus a storage node (this storage node is represented by value 0)
- T set of transmission facility types t
- Y_i^t demand values: number of transmission facilities of type $t \in T$ starting/ending on node $i \in N$
- R set of router models r
- M_r number of available slots of router model r
- K_t set of available network cards with transmission interfaces of type $t \in T$
- P^{tk} number of transmission interfaces (of type t) on each network card of type $k \in K_t$
- R_i^r number of routers of model $r \in R$ that exist in node $i \in N$
- E_i^{tk} number of cards of type $k \in K_t$ that exist in node $i \in N$
- C^r acquisition cost of a router model $r \in R$
- C_{ij}^r cost of transferring a router model r from node $i \in N$ to node $j \in N$
- C^{tk} acquisition cost of a network card of type $k \in K_t$
- C_{ij}^{tk} cost of transferring a network card of type $k \in K_t$ from node $i \in N$ to node $j \in N$

Consider also the following variables to the problem:

- x_i^r binary variable that indicates if a router of model $r \in R$ is to be acquired for node $i \in N$
- x_{ij}^r binary variable that indicates if a router of model $r \in R$ is to be transferred from node $i \in N$ to node $j \in N$
- y_i^{tk} number of network cards of type $k \in K_t$ to be acquired for node $i \in N$
- y_{ij}^{tk} number of network cards of type $k \in K_t$ to be transferred from node $i \in N$ to node $j \in N$

Note that in this notation, a special storage node represented by value 0 implicitly models the storage of the equipment. Therefore, for this special node the demand values Y_0^t for all $t \in T$ are all zero.

The node dimensioning problem is defined as:

Minimise:

$$\sum_i \sum_r C^r \cdot x_i^r + \sum_i \sum_t \sum_k C^{tk} \cdot y_i^{tk} + \sum_i \sum_{j \neq i} \sum_r C_{ij}^r \cdot x_{ij}^r + \sum_i \sum_{j \neq i} \sum_t \sum_k C_{ij}^{tk} \cdot y_{ij}^{tk}$$

subject to:

$$\text{(a)} \quad \sum_k \left[P^{tk} \cdot \left(y_i^{tk} + E_i^{tk} + \sum_{j \neq i} \left(y_{ji}^{tk} - y_{ij}^{tk} \right) \right) \right] \geq Y_i^t, \quad \forall t \in T, \forall i \in N \setminus \{0\}$$

$$\text{(b)} \quad \sum_r \left[M_r \cdot \left(x_i^r + R_i^r + \sum_{j \neq i} \left(x_{ji}^r - x_{ij}^r \right) \right) \right] \geq \sum_t \sum_k \left[y_i^{tk} + E_i^{tk} + \sum_{j \neq i} \left(y_{ji}^{tk} - y_{ij}^{tk} \right) \right], \quad \forall i \in N \setminus \{0\}$$

$$\text{(c)} \quad \sum_r \left(x_i^r + R_i^r + \sum_{j \neq i} \left(x_{ji}^r - x_{ij}^r \right) \right) \leq 1, \forall i \in N \setminus \{0\}$$

$$\text{(d)} \quad \sum_{j \neq i} x_{ij}^r \leq R_i^r, \forall r \in R, \forall i \in N$$

$$\text{(e)} \quad \sum_{j \neq i} y_{ij}^{tk} \leq E_i^{tk}, \forall t \in T, \forall k \in K_t, \forall i \in N$$

$$\text{(f)} \quad x_i^r \in \{0,1\}, x_{ij}^r \in \{0,1\}, y_i^{tk} \text{ integer}, y_{ij}^{tk} \text{ integer}$$

The minimisation function is the upgrade cost of the solution: the first term is the router total acquisition cost, the second term is the router total transfer cost, the third term is the network card total acquisition cost and the last term is the network card total transfer cost.

Constraints (a) guarantee that, for each routing site and each type of transmission facility, the set of network cards in the final solution has at least the number of interfaces required by the demand value. Note that in the left end side of these constraints, the set of network cards is equal to the set of acquired cards plus the set of existing cards plus the set of cards transferred from the other nodes minus the set of cards transferred to other nodes.

Constraints (b) guarantee that, for each routing site, the set of routers in the final solution has enough slots to plug the required network cards given by constraints (a). In the left end side of these constraints, the set of routers is equal to the set of acquired routers plus the set of existing routers plus the set of routers transferred from the other nodes minus the set of routers transferred to other nodes.

Constraints (c) guarantee that the solution of the problem will have at most one router per routing site.

Constraints (d) guarantee that the number of routers of each type to be transferred from any routing site cannot be higher than the existing number of routers.

Similarly, constraints (e) guarantee that the number of network cards of each type to be transferred from any routing site cannot be higher than the existing number of cards.

This integer linear programming problem is efficiently solved through a standard branch-and-bound algorithm for problem instances of relevant size.

3 Case study

In this section, we consider a case study of a typical Internet Service Provider (ISP) network composed by different Points-of-Presence (POPs). The case study network has 15 POPs and each POP has 6 access routers and 2 core routers as shown in Fig. 1 and 2 (which are captures of PTPlan MPLS tool [6]).

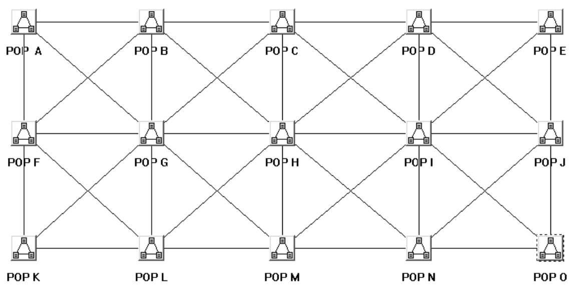

Fig. 1 Network structure

The MPLS domain considers the core routers of each POP as the Ingress/Egress MPLS LSRs. A similar case study was studied in [8] for the MPLS domain definition. Our approach considers a single MPLS domain where POP core routers the Ingress/Egress LSRs. In their case, POP access routers are the Ingress/Egress LSRs and a 2-layer hierarchical MPLS domain solution was adopted to prevent the explosion on the number of LSPs.

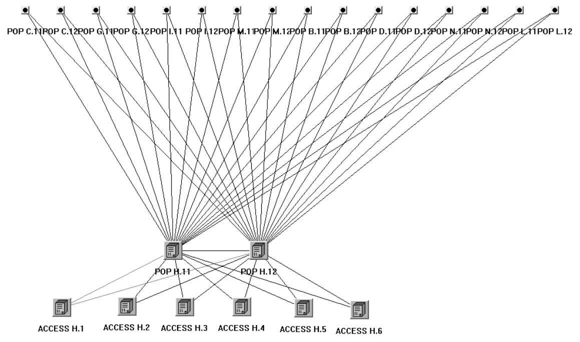

Fig. 2 POP structure

On each POP, each access router is connected to each core router through one Unchannelized E-3 link (this part of the network is fixed). Graph links between core routers mean that transmission facilities can be set between the routers in the link dimensioning problem. We consider the following transmission facility types: Unchannelized E3, OC3c/STM-1 and OC12/STM-4, with the following O&M costs:

	Bandwidth (Mbps)	Routing cost	Transmission cost (per length unit)
Unchannelized E3	33.92	10	0.2
OC3c/STM-1	149.76	30	
OC12/STM-4	599.04	100	

The O&M cost of each transmission facility is given by 2 × (routing cost) + (transmission cost) × (length of the link). In our example, link lengths vary between 200 and 283.

In the node dimensioning problem, we consider two MPLS router models that can be installed in each network node. In both router models, network cards can be plugged in one of their cards slots. The two router models differ in the number of free slots. The number of transmission interfaces of each network card depends on the transmission facility type. In the following tables, the acquisition costs and the physical characteristics of both router models and network cards are presented:

	LSR A	LSR B
Acquisition Cost (per unit)	5000	8000
No. of Slots	5	12

	E3	STM-1	STM-4
Acquisition Cost (per unit)	300	600	1000
No. of Transmission Interfaces	3	2	1

We consider router transfer costs of 200 between all routing sites and card transfer costs of 25 also between all routing sites. Additionally, we consider a router transfer cost of 200 for the storage node and a negligible card transfer cost for the storage node.

Since the POP internal connections are fixed, the dimensioning task can be simplified by replacing the 6 access routers by a single access router with aggregate demand bandwidths for other POPs which are the sum of all individual access router demand bandwidths. We have considered two peer-to-peer services and two time periods. In the initial dimensioning cycle, the aggregate bandwidth for each service, each time period and each pair of POPs was randomly generated between 0 and 6 Mbps for the first service and between 0 and 12 Mbps for the second service, with a uniform distribution. For the subsequent dimensioning cycles, an increment of each bandwidth value was randomly generated between –5% and 45% giving an average traffic growth of 20%. Colours were assigned to LSPs and links in order to prevent LSPs from crossing the interior of other POPs. For all dimensioning cycles, we have considered two node disjoint survivability degrees: 50% and 100%. The following table summarises the dimensioning results that were obtained.

		Node survivability 50%		Node survivability 100%	
		Uni Hour	Multi hour	Uni Hour	Multi Hour
Cycle 1	O&M Cost	7555	7235	8621	8188
	Investment Cost	185100	183300	197400	199500
Cycle 2	O&M Cost	7895	7735	9154	8588
	Investment Cost	22450	13625	20875	2500
Cycle 3	O&M Cost	8268	8115	9518	8964
	Investment Cost	1550	13025	*20425	3275
Cycle 4	O&M Cost	8448	8231	9798	8978
	Investment Cost	3000	3675	23350	18275

In this table, the uni-hour solution was obtained considering the aggregate bandwidth between each pair of POPs as the worst of the bandwidth values of the two time periods. As expected, gains are obtained when adopting a multi-hour approach. An interesting aspect shown by the results is that the provision of 100% survivability only increases O&M costs by 15.3% in the uni-hour case and 10.9% in the multi-hour case over the cost of providing only 50% of survivability.

Link dimensioning was done using PTPlan MPLS tool [6] and the link dimensioning computing times were less than one minute for all cases. For node dimensioning problems, CPLEX [9] was used to run the branch-and-bound algorithm and all cases except one were solved up to the optimality in seconds (using aggressive cut insertion and strong branching in variable selection). The exception was the one with symbol * that did not find the optimal solution in 10 minutes. Note that the node dimensioning results are higher for the first period since there was no installed equipment at the beginning.

4 Conclusions

Previous approaches in the literature have addressed only the link dimensioning problem without further consideration on the dimensioning of network nodes. This paper has presented a combined approach to the two problems. We have presented a case study based on a typical ISP network where the dimensioning task is applied whenever a new dimensioning cycle starts. The link dimensioning problem is too complex to be solved by standard solvers [10] and an already known heuristic was applied to solve it. On the other hand, the case study has shown that standard solving techniques for Integer Linear Programming problems can be used to resolve the node dimensioning problem for realistic instances since optimal solutions were obtained in short computing times for almost all cases. The presented results were obtained using a beta version of PTPlan MPLS tool that is currently being upgraded to deal with node dimensioning.

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