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Learning automata-based CPU non-intensive calculation of dedicated and shared protected paths in bandwidth-guaranteed networks

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ABSTRACT

In survival networks, end-to-end protected connections can be based on dedicated protected paths (DPPs) or shared protected paths (SPPs). DPPs allow a short period of service interruption, while SPPs reduce spare capacity. Some algorithms have been developed for the dynamic establishment/release of bandwidth-guaranteed protected paths under distributed control. These algorithms have the drawback of high computational complexity. Therefore, a learning automata based hierarchical model for CPU non-intensive calculation of protected paths is proposed. In this case, protected paths are calculated quickly without requiring global link status information. This model also allows the optimization of the total bandwidth through (1) the joint selection of SPPs or DPPs and (2) the preference in choosing short paths with wide available bandwidth. The results show a low computational complexity compared with existing algorithms and a significant performance improvement in SPPs with respect to DPPs because of the removal of the spare bandwidth by SPPs.

1. Introduction

A key issue of design in backbone networks is the introduction of control mechanisms that allow the dynamic establishment of PP [1,2]. There is currently an increase in requests for dynamic protected connections due to the heavier traffic that comes from the Internet. Additionally, the calculation algorithms for PP have shown increasing complexity. This represents a significant challenge for Internet transport networks due to the high burden in terms of computational power they need to support. The processing load from the execution of such algorithms is necessary to mitigate. Furthermore, a scalable approach in calculating PP is also necessary, due to the dimensions of the Internet and its growth in size [3]. Then, this work focuses on the dynamic provisioning of guaranteed-bandwidth PP with CPU non-intensive calculation under distributed control.

In distributed control, distributing the information for link usage is necessary throughout the entire network. Each network node is thus provided with updated link usage information on all the links on the network. This is known as *global link status information*. The calculation overhead of PP is due to the selection overhead of PP itself and also to updating of the global link usage information. Here, PP selection is performed in a probabilistic manner without taking the global link status information into account. The distribution of link usage information between network nodes is done by extension of signalling protocols. In this way each network node is provided with the updated information on certain network links. This implies a reduction of the computational load that entails loss of accuracy in calculation of PP.

The definition of Path Computation Element (PCE) [4,5] allows reducing the processing load on the dynamic provisioning of PP by segmenting the network into domains. Calculation of the path is delegated to the PCE, which separates it from the other functions of the MPLS control drawing. The problem with using PCE is the high cost in research and resources required to tackle issues that are still pending in their integration into MPLS. In this case the processing load is reduced by simplification of the computational complexity in a cost-effective manner. Here, MPLS is limited by the fact that signalling protocols (e.g., RSVP-TE [6]) do not have the extensions that are necessary for the establishment of SPP. In addition, the calculation simplicity should allow for the greatest possible number of future protected connections to obtain the maximum revenue. Thus, both simplicity and the optimal bandwidth efficiency are necessary in calculating PP. Hereafter, the term “connection” refers to protected connections with guaranteed bandwidth.

Survival techniques have had great consideration in recent years in high-capacity networks because any edge/node failure in these networks means a huge loss of data. A single failure treatment has advantages over multiple failures [7,8], regarding the reduced use of resources, making it more probable that a single failure oc-

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Nomenclature

b	bandwidth amount requested by a connection
s	node source (or ingress)
d	node destination (or egress)
S	set of edge-disjoint paths between (s, d)
N	number of paths in S
l_i	ith AP from $S = \{l_i\}_{1 \le i \le N}$
l_{ij}	jth BP from $S' = S - l_i,\ 1 \le j \le N-1$
$\|l_i\|$, $\|l_{ij}\|$	number of hops on l_i and l_{ij}
M	$M = 2 \cdot \max\{\|l_i\|\}_{1 \le i \le N}$
ϕ_{ij}	set of PP $\phi_{ij} = \{l_i, l_{ij}\}$
$c_i(n)$, $c_{ij}(n)$	blocking probabilities of l_i and l_{ij}
$c_i(\boldsymbol{p})$, $c_{ij}(\boldsymbol{p}_i)$	$c_i(\boldsymbol{p}) = c_i(n)$ and $c_{ij}(\boldsymbol{p}_i) = c_{ij}(n)$
ABW	Active path bandwidth
AP	Active path
APF	Active path first
BBW	Backup path bandwidth
BP	Backup path
DPP	Dedicated protected paths
PP	Protected paths
SPP	Shared protected paths
TBW	Total bandwidth

curs. Here, a single-failure connection request arrives at s for the establishment/release of AP and BP with destination d. Once AP and BP are established, information is transmitted by AP, and in the case of failure, by BP. Both paths will be considered edge disjoints, although the solutions presented can be generalized to the case of node-disjoint paths. The single-failure solution with the least amount of data loss due to interruption of service is DPP, in which the transmitter transmits simultaneously by the AP and BP. In this case, the receiver is able to detect a failure and act quickly, by selecting the path with the strongest signal. Although DPP is the quickest solution to react to a failure, also it involves a high spending of spare bandwidth. However, SPP [9–11] represent a cost-effective solution because bandwidth from a BP can be shared by several connections.

1.1. Problem description

In this section, the procedures for establishing DPP and SPP will be described. For this, the requested connections will require $b = 1$. Let us consider Fig. 1(a), in which the available bandwidth is initially one unit for all of the edges, whereas the initial availability in Fig. 1(b) is two units. When using DPP, the network of Fig. 1(a) does not have sufficient bandwidth for two connections between A and D, but for a single connection, ABD would be the AP and AED would be the BP. However, if SPP are employed, once SPP1 is established, there is available bandwidth to establish a second connection SPP2, according to Table 1. Because we assume that only a simultaneous failure may occur, AP of SPP1 and AP of SPP2 cannot

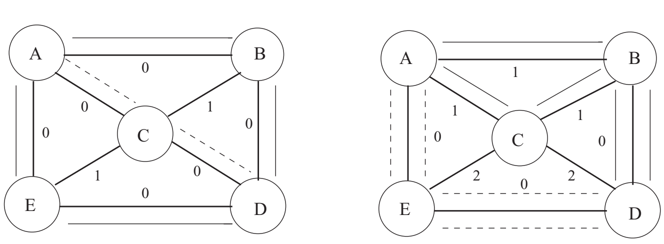

Fig. 1. (a) Edge-disjoint APs and (b) APs with common edge.

Table 1
All SPP established in Fig. 1.

Connection	AP	BP	ABW	BBW
(a)				
SPP1	A-B-D	A-C-D	2	2
SPP2	A-E-D	A-C-D	2	0
(b)				
SPP3	A-C-B-D	A-E-D	3	2
SPP4	A-B-D	A-E-D	2	2

break at once because they are disjoint. Then, because a BP can be shared by both APs, BBW of SPP2 is zero. In Fig. 1(b), the case of two APs with a common edge is shown. In this case, it is not feasible to establish a shared BP because if the common edge failed, only one AP could be restored. Then, for both APs to be protected, two BPs are set up, i.e., one assigned to each AP. As a result, unlike Fig. 1(a), both BBWs are greater than zero. It can also be verified that the values of ABW from Table 1 also correspond to values of Fig. 1.

Before discussing the several strategies to optimize bandwidth, TBW is defined as the sum of ABW and BBW, which is necessary for the establishment of PP, belonging to a set of satisfied connection requests. Solutions based on the joint selection of PP are the ones that allow the minimization of TBW by optimizing simultaneously both the ABW and BBW in treating each connection. These algorithms have the disadvantage of high processing time for each connection. Regarding APF, a lower minimization of TBW is shown because it is not performed simultaneously for both PP, but rather in two stages. The AP is obtained first, regardless of the BP, which is obtained later. Then, ABW reduction is performed first and subsequently BBW is reduced, once AP is known.

The problem of finding SPP jointly under the current state of the network is NP-complete [12]. A heuristic that can quickly and simultaneously calculate SPP is proposed to minimize TBW. In this work, it is assumed that all requests for set up and release do not arrive at the same time. The establishment of PP is carried out dynamically without knowing the future connection requests and without being able to rearrange the way that previous PP are established. If a rearrangement was carried out, this would imply that the proposed model would not meet the requirement of a rapid response to requests.

Global link status information is required for each s to perform distributed routing. Therefore, each network node sends link-state routing advertisements (e.g., by OSPF-TE [13]) both periodically and when a significant change occurs in the link state. The computational complexity in each s includes calculating the SPP or DPP itself, as well as updating databases that store the corresponding global link status information. As for changes in network status, a high rate of link-state advertisements is a heavy processing load for the maintenance of databases. Furthermore, with higher values of the connection establishment/release rates and/or larger size of the network, higher values are obtained for the rate of those advertisements. Then, an algorithm that allows, in all situations, for maintaining the changes in the link states without a high link-state advertisement rate is required.

1.2. Proposed model

In this section, a learning model that allows interaction with the communications network is considered. The learning is based on success or failure in establishing the PP from connections previously requested. Additionally, the exchange of global link status information is not necessary to have an effective utilization of TBW. As for the simultaneous election of AP and BP, a way to obtain this feature is through the collaboration of two learning automata in