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On the problem of capacity allocation and flow assignment in self-healing ATM networks

Isaac Woungang [a,*], Sudip Misra [b], Mohammad S. Obaidat [c]

[a] *Department of Computer Science, Ryerson University, Toronto, ON, Canada*
[b] *Department of Computer Science, Yale University, New Haven, CT, USA*
[c] *Department of Computer Science, Monmouth University, West Long Branch, NJ, USA*

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Abstract

In the current overlay transport networks, IP/ATM/SONET/DWDM, each layer manages its own control plane, each control plane acting independently of what happens in the other. In the course of recent years, the generalized multi-protocol label switching (GMPLS) has emerged as the new unified control plane for all the above transport layers. As such, the already installed ATM core resource management features must be reused as a particular implementation of GMPLS, either directly or with some adaptations. Among such transferable research work are studies related to the problem of capacity allocation and flow assignment in self-healing ATM networks. This problem has been investigated by many authors, using two main design approaches: the path-based and the link-based approaches. In the path-based design approach, the focus in almost all proposed solutions has been to determine the optimal spare capacity and backup virtual paths (BVPs) allocation for all traffic flows. To our knowledge, no study has been done to quantify the impact of the selection of BVPs on the optimized spare capacity allocation (SCA). In this paper, we address this issue by comparing four SCA design schemes quantitatively in terms of spare capacity requirements (SCRs). The comparison is based on spare optimization, a single link failure or node failure scenario, and 100% restoration. We also introduce a link-based design approach of the above problem and show that the solution obtained is adequate in terms of grade of service and quality of service requirements.

Keywords: ATM network design; Flow assignment; Spare capacity allocation; Self-healing; Link-based approach; Path-based approach

1. Introduction

A telecommunication network is composed of three parts: a subscribers' network, a traffic network, and a physical (or transmission) network (PN). The reliability of such network is a key challenge to the network research community [1]. To cope with this issue, network architects, and planners have resorted to the construction of self-healing networks, i.e., a network in which a restoration procedure is setup to quickly and automatically respond to network failures (link or node failure), by reconfiguring connections using spare capacity which has been installed in advance for such contingencies [2–4]. Technologies and techniques that have been employed to provide reliable communications include: physical diversity, facility duplication, and switching on a hot stand-by basis using add drop multiplexers (ADMs), digital cross-connects (DCSs) in the Plesiochronous digital hierarchy (PDH), synchronous networks (SONET), and synchronous digital hierarchy (SDH) cross-connects, transmission systems deployed in self-healing rings or mesh networks, ATM switching systems, alternate and dynamic routing at the traffic layer, and more recently, GMPLS. These technologies and techniques can be employed to provide a self-healing capability in networks dimensioned according to either the path-based design approach ([2] and the references therein) or the link-based design approach [8,9]. In the *path-based* design approach, a complete mesh of virtual paths (VPs) is established among origin and destination nodes. Virtual circuits (VCs) between end points are multiplexed/de-multiplexed by edge VC switches onto (and from) corresponding VPs linking the same endpoints. Since the

* Corresponding author.
E-mail address: iwoungan@scs.ryerson.ca (I. Woungang).

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underlying PN is typically not fully connected, several such VPs can share the same link of the PN, and VP cross-connects are required at junction points of the PN to route incoming VPs to the appropriate outbound physical link. In this approach, a single path supports all traffic between endpoints, thus, the network is vulnerable to link or node failures, and thus, mandates the need for a spare network and restoration procedures to be invoked when a failure event occurs. In the *link-based* design approach, VPs are also defined end-to-end. However, bandwidth is managed on a *virtual link* basis [9], and multiple VPs linking the same endpoints are used as alternate routing paths. The provision of the self-healing capability in the PN also depends on the restoration schemes and the type of reconfiguration methods used in the network. There are two types of restoration schemes: (1) reactive restoration schemes, where the search for spare capacity starts after a failure occurs, by broadcasting restoration messages, and (2) preplanned restoration schemes, where all restoration routes are pre-computed by, for instance, the network management centre, for given failure scenarios. In case of failure, a node responsible for restoring affected traffic knows exactly where to find the required spare capacity. Two types of reconfiguration schemes exist: (a) failure-oriented reconfiguration, where only the affected working VPs are rerouted upon failure of a link or node in the PN, and (b) global reconfiguration, where the whole layout of working VPs (affected and non-affected) may be re-arranged to avoid a failed link or node. In addition, a restoration mechanism is categorized either as a link-based restoration scheme (i.e., only the two nodes connected to the failed link are involved in the restoration process) or as a path-based restoration scheme (i.e., the two endpoints of each failed working VP are involved in the restoration process). The problem of capacity allocation and flow assignment in self-healing mesh-type networks was studied in [5,10,11] for link-based restoration, and in [7,12], for global reconfiguration, path based restoration. Using the multi-commodity flow model as reported in [10,6,11], we can formulate the problem as a linear programming problem. The algorithms described there give optimal solutions for SCA. However, the corresponding optimal flow assignments are only available in [6] and [11], not in [10]. Node failure scenarios and hop-limit constraints are also considered in [11]. A practical and near-optimal algorithm was developed in [5] for SCA, which uses *k*-shortest link disjoint paths for traffic rerouting. The above problem was studied in [12] as a non-simultaneous multi-commodity flow model. An efficient sub-optimal solution procedure was presented which is suitable for large-scale networks, but as in [10], no flow assignment is provided. The work in [7] formulated the same problem as a mixed integer linear programming problem. Their upper and lower bounding techniques can only be applied to small- and moderate-scale networks. Unlike previous works reported, the path-based design approaches presented in [2] and [8] focused mainly on failure-oriented restoration and state-dependent backup VP scheme [21]. A heuristic scheme known as "the Minimum Cost Route" (MCR) algorithm was also developed in [2], mainly for the non-bifurcated flow case. This algorithm does not use any optimization method, thus is suitable for very large-scale networks with path restoration. For this reason, we will use the path-based integer programming (IP) formulation and the MCR algorithm described in [2,8]. Based upon the optimal solutions obtained from this IP formulation, we will compare quantitatively four SCA design schemes, determined by the following BVPs selection options: (1) The second shortest disjoint path for the BVP, (2) One of the shortest disjoint paths for the BVP, (3) Joint selection of working VPs and BVPs among shortest disjoint paths, and (4) Joint selection of working VPs and BVPs among all possible paths. The comparison is based on spare optimization, single link or node failure scenario, state-dependent path restoration, and 100% restoration for the predefined failure scenario. For the link-based design approach, we will use a modified version of the mathematical model described in [13] because it is suitable for the purpose of our study. In this model, an ATM network is treated as a multi-rate circuit-switched network [15]. In that case, the end-to-end blocking probability of a connection will be used as the network's performance measure, rather than the packet transmission delay. This is justified by the notion of effective bandwidth, which establishes a correspondence between the packet level and the connection level, while guaranteeing the performance of the network at the cell level [14–26].

The rest of the paper is organized as follows. The *path-based* design approach is presented in Section 2, along with a comparison of the aforementioned SCA design schemes. The *link-based* design approach is presented in Section 3, and some properties of the solution obtained in terms of feasibility, transmission network cost, and network performance, are presented. Section 4 concludes our work.

2. Path-based design approach

In the path-based design approach [2], the network is modeled as a two level network: the physical network and the spare network. The bandwidth is managed by means of VPs. Using the distance between two nodes as a metric, the shortest path routing is used as the BVPs routing method, assuming that all working VPs take the shortest routes to their destination (this is referred to as spare optimization). We consider the state-dependent preplanned restoration. In this case, a working VP may have more than one BVP. The selection of a particular BVP when the working VP fails depends on many factors such as the network failure state and the spare capacity on the arcs of potential BVPs [22]. Given a network failure scenario, i.e., a single link or a single node failure, the restoration of affected traffic takes place at the VP level. Since the spare capacity is shared among BVPs of non-simultaneously failed working VPs, it is an interesting problem to quantify the impact that the selection of these BVPs might have on the optimized SCA. This paper studies the problem and compares the four SCA design schemes described earlier