Designing Networks with Existing Traffic to Support Fast Restoration

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Abstract. We study a problem motivated by a scheme for supporting fast restoration in MPLS and optical networks. In this local restoration scheme detour paths are set-up a priori and network resources are pre-reserved exclusively for carrying rerouted traffic under network failures. (i.e. they do not carry any traffic under normal working conditions). The detours are such that failed links can be bypassed locally from the first node that is upstream from the failures. This local bypass activation from the first detection point for failures along with the dedication of network resources for handling failures permits very fast recovery times, a critical requirement for these networks. By allowing sharing of the dedicated resources among different detours the local restoration scheme results in efficient utilization of the pre-reserved network capacity.

In this paper we are interested in the problem of dedicating the least amount of the currently available network capacity for protection, while guaranteeing fast restoration to the existing traffic along with any traffic that may be admitted in the future. We show that the problem is NP-hard, and give a 2-approximation algorithm for the problem. We also show that the integrality gap of a natural relaxation of our problem is Ω(n), thus establishing that any LP-based approach using this relaxation cannot yield a better approximation algorithm for our problem.

1 Introduction

Dynamic provisioning of bandwidth guaranteed paths with fast restoration capability is an important network service feature for the emerging Multi-Protocol Label Switched (MPLS) networks [7] and optical mesh networks [18]. The fast restoration capabilities are required in order to provide the needed reliability for services such as packetized voice, critical VPN traffic, etc. Traditionally ring based SONET [11] networks have offered 50ms restoration to bandwidth guaranteed services, using pre-reserved spare protection capacity and pre-planned protection paths. Pre-planning protection in rings has been especially attractive, because of the availability of exactly one backup path between any two nodes, leading to very simple and fast automatic protection switching mechanisms. However in ring based SONET networks these advantages come at the cost of reserving at least half the total capacity for protection.

A local restoration scheme [12], [16], [20] is proposed to provide fast restoration in mesh based MPLS and optical networks. In this scheme which is also referred to as
link restoration the traffic on each link \( e \) of the network is protected by a detour path that does not include link \( e \). Upon failure of any link \( e \), any traffic on \( e \) is switched to its detour path. Thus, link restoration provides a local mechanism to route around a failure. In this restoration scheme the restoration capacity of the pre-setup detours is not used under normal no-failure conditions (except possibly by low priority preemptible traffic). Local restoration when used in conjunction with advanced reservation of the restoration capacities and pre-setup detours results in low restoration latency. Pre-provisioned link restoration also results in operational simplicity since the detours have to be only provisioned once for a given network topology and since the online connection routing can now be done oblivious to the reliability requirements, using only the resources that are not reserved for restoration.

An important consideration for any fast restoration scheme is to minimize the network resources dedicated for restoration and hence to maximize the proportion of network resources available for carrying traffic under normal working conditions. In general, link restoration provides guaranteed protection against only single link failures hence the reserved restoration capacity may be shared among the different pre-setup detours (since at most one detour may carry restored traffic at any given time). Thus pre-provisioned link restoration scheme offers the promise of fast restoration recovery for just a small fraction of the total capacity reserved for restoration, due to the high degree of restoration capacity sharing that is possible in mesh networks.

In many situations one would like to support fast restoration on existing networks without disturbing the existing traffic, meaning that the restoration scheme can only use up to the current available network capacity (link capacity minus existing traffic capacity) for protecting the existing traffic and any new traffic. Note that existing traffic makes the problem harder. A simpler polynomial-time 2-approximation algorithm in the absence of existing traffic was presented in [1] (see Related Work).

In this paper we are interested in the optimization problem of dedicating the least amount of the currently available network capacity for protection, while guaranteeing fast restoration to the existing traffic along with any traffic that may be admitted in the future, for the pre-provisioned link restoration scheme. Specifically we are interested in partitioning the available link capacities into working and protection, such that the latter is dedicated for restoration and the former is available to carry any current or new traffic, with the objective of guaranteeing link restoration for minimal total protection capacity. Note that in a network with a static topology this problem may need be solved only once, since the solution remains feasible even as the admitted traffic pattern changes. However, the solution may not stay optimal over time as the admitted traffic pattern changes, and may be recomputed occasionally to ensure efficient utilization of network resources. Also changes in network topology (which are common but not frequent) may require recomputing the solution, since the old solution may not even guarantee link restoration.

### 1.1 Problem Definition

Given a undirected network \( G = (V, E) \), with link capacities \( u_e \) and existing traffic \( W_e \) on link \( e \in E \) the problem is to partition the capacities on link \( e \) into a working capacity \( w_e \) and a protection capacity \( p_e \) (s.t. \( w_e + p_e = u_e \)) such that