# Algorithms for Computing QoS Paths with Restoration

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**Abstract**

There is a growing interest among service providers to offer new services with *Quality of Service* (QoS) guaranties that are also resilient to failures. Supporting QoS connections requires the existence of a routing mechanism, that computes the *QoS paths*, *i.e.*, paths that satisfy QoS constraints (*e.g.*, delay or bandwidth). Resilience to failures, on the other hand, is achieved by providing, for each primary QoS path, a set of alternative QoS paths used upon a failure of either a link or a node. The above objectives, coupled with the need to minimize the global use of network resources, imply that the cost of both the primary path and the restoration topology should be a major consideration of the routing process.

We undertake a comprehensive study of problems related to finding suitable restoration topologies for QoS paths. We consider both bottleneck QoS constraints, such as bandwidth, and additive QoS constraints, such as delay and jitter. This is the first study to provide a rigorous solution, with proven guaranties, to the combined problem of computing *QoS paths* with *restoration*. It turns out that the widely used approach of disjoint primary and restoration paths is not an optimal strategy. Hence, the proposed algorithms construct a *restoration topology*, *i.e.*, a set of *bridges*, each bridge protecting a portion of the primary QoS path. This approach guaranties to find a restoration topology with low cost when one exists.

In addition to analysis, we test our approach also by way of simulations. The simulation results demonstrate that our proposed approximation algorithms identify QoS restoration paths whose cost is significantly smaller than those provided by alternative approaches.

**Index Terms**

Restoration, OoS routing, Approximation algorithms.

## I. Introduction

There is a growing interest among service providers to offer their customers new revenue-generating services with *Quality of Service* (QoS) guarantees. This is facilitated by current efforts to provide resource reservations and explicit path routing, *e.g.*, *MultiProtocol Label Switching* (MPLS). A key requirement for such services is that they also be resilient to failures. This goal can be achieved by provisioning *primary* and *restoration* paths that satisfy the QoS constraints. The primary QoS path is used during normal network operation; upon failure of a network element (node or link) in the primary path, the traffic is immediately switched to a restoration path. To facilitate this seamless recovery to a restoration path in the event of a failure, it is necessary to reserve network resources (*e.g.*, bandwidth) on both the primary and restoration QoS paths. Thus, since optimizing the utilization of network resources is an important requirement for service providers, it is crucial that the *cost* of the computed primary and restoration QoS paths be as small as possible, where the cost of a path is some measure related to the characteristics of its links, their degree of utilization, *etc*.

QoS constraints occur naturally in a number of practical settings involving bandwidth and delay sensitive applications such as voice over IP, audio and video conferencing, multimedia streaming *etc*. For instance, voice (*e.g.*, telephone conversations) requires a certain bandwidth allocation along the connection path (currently, around 16–64 Kbs) and the end-to-end path delay to be below a certain threshold (typically between

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