A Survey of QoS Routing Algorithms

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***Abstract*—** There is an obvious need for Quality of Service (QoS) on the Internet and QoS routing is an important component of the overall QoS framework. The role of a QoS routing strategy is to compute paths that are suitable for the different types of traffic generated by the various applications, while maximizing the utilization of network resources. The fulfilment of these objectives requires the development of algorithms that find multi-constrained paths taking into consideration the state of the network and the traffic requirements, namely, considering its needs in terms of delay, jitter, loss rate and available bandwidth. However, the problem of finding multi-constrained paths has high computational complexity, and thus there is the need to use algorithms that address this difficulty. This paper presents and discusses the main approaches used to reduce QoS routing algorithm complexity and to improve the overall network performance.

***Keywords*—**Complexity, QoS routing algorithms.

I. Introduction

THE path computation algorithm is at the core of QoS routing strategies. Instead of using a shortest path algorithm based on statically configured metrics, as in traditional routing protocols, the algorithm must select several alternative paths that are able to satisfy a set of constraints regarding, for instance, end-to-end delay bounds and bandwidth requirements. However, the algorithms to solve such a problem have been shown to have, in general, high computational complexity. Several approaches have been proposed to address the complexity of multi-constrained path computation problem. The selection of QoS paths subject to multiple constraints can be defined as the Multi-Constrained Path (MCP) problem. In order to present the definition of the MCP problem, some definitions are introduced, as follows: a network is represented by a directed graph $G(V,E)$ composed of a set of vertices (V) and a set of edges (E). The number of vertices of G is given by $n = |V|$ and the number of edges is given by $m = |E|$. Each edge, is represented by the link between two vertices $e = (u,v)$ and has associated q weights corresponding to QoS metrics such that $w_i(u,v) >= 0$, and $i = 1,2,\dots,q$. The constraint for each QoS metric is L_i. The *Multi-Constrained Path problem* is to find a path P from a source s to a destination d such that all the QoS constraints are met, as depicted in the following equation:

$$w_i(P) \le L_i, \quad i = 1,2,\dots,q \qquad (1)$$

The paths that satisfy these constraints are called *feasible paths* [1]. The solution of the MCP problem requires a path computation algorithm that finds paths that satisfy all the constraints as expressed in Equation 1. Since the optimal solution of this type of problems for multiple additive and independent metrics is NP-complete, usually heuristics or approximation algorithms are used.

The first approach considered is used when bandwidth is one of the constraints that must be satisfied by the path computation algorithm. In this case, the MCP problem is defined as a Bandwidth Restricted Path (BRP) problem [2].

The second approach is called Restricted Shortest Path (RSP) and is a simplification of the original MCP problem, when two additive metrics are used [1]. In this case, all the paths that satisfy the constraint associated with one of the metrics are computed and then the best path according to the second metric is selected.

Metrics Combination (MC) is the third approach for the solution of the MCP problem [3]. By combining a set of QoS metrics in a single metric, it is possible to use existing path computation algorithms, such as Bellmand-Ford or Dijkstra.

Algorithms that solve the multi-constrained path problem using the above strategies are described in the following sections.

II. Bandwidth Restricted Paths

Bandwidth is widely used as a metric for QoS routing, alone or associated with other metrics, such as delay or number of hops [4]. The utilization of bandwidth in association with other metric simplifies the original MCP due to the fact that it is a concave metric that has a non-cumulative composition rule over a path. *Metric Ordering* is one of the main heuristics used for the solution of the BRP problem. This heuristic requires the identification of the metric that has higher priority and the computation of the best paths according to this metric. Afterwards, it is computed the best path according to the second metric. The algorithms that solve the BRP problem using metric ordering are the Widest-Shortest Path (WSP) and Shortest-Widest Path (SWP) algorithms. In these families of algorithms, the width of a path is depicted by the available bandwidth and its length can correspond either to the number of hops or to delay. The nature of the delay that is used for

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