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A Pareto-based hybrid multiobjective evolutionary approach for constrained multipath traffic engineering optimization in MPLS/GMPLS networks

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ABSTRACT

This paper proposes a hybrid evolutionary algorithm for solving the constrained multipath traffic engineering problem in MPLS (Multi-Protocol Label Switching) network and its extended architecture GMPLS (Generalized MPLS). Multipath traffic engineering is gaining more importance in contemporary networks. It aims to satisfy the requirements of emerging network applications while optimizing the network performance and the utilization of the available resources within the network. A formulation of this problem as a multiobjective constrained mixed-integer program, which is known to be NP-hard, is first extended. Then, we develop a hybrid heuristic algorithm based on combining linear programming with a devised Pareto-based genetic algorithm for approximating the optimal Pareto curve. A numerical example is adopted from the literature to evaluate and compare the performance of six variations of the proposed heuristic. We study the statistical significance of the results using Kruskal–Wallis nonparametric test. We also compare the results of the heuristic approach with the lexicographic weighted Chebyshev method using a variety of performance metrics.

1. Introduction

Multipath traffic engineering is becoming more appealing for Internet Service Providers (ISPs); it may have significant impact on the network performance while satisfying the required service quality for emerging network applications. In contemporary networks, traffic is increasing exponentially, but resources, including bandwidth, are very scarce. Hence, efficiently mapping traffic onto the physical network is substantially important for satisfactory network operation. Splitting and forwarding a traffic demand onto multiple paths can overcome many of the functional limitations of the traditional routing algorithms which forward traffic over the shortest path from the source to the destination. For example, multipath routing can balance traffic distribution over different paths, avoid congested links, increase robustness, minimize packet loss rate, bound delay and delay jitter, increase utilization of resources, and consequently provide better quality of service for potential network applications. From optimization perspective, this problem involves multiple objectives and constraints by nature which consequently increases its computational complexity. Thus, studying the tradeoffs between different objectives can result in a better heuristic that can help speed up the search for an approximate feasible solution (Wang et al., 2008; Garroppo et al., 2010; Balon et al., 2006).

In this paper, we focus on multipath routing in MPLS (Multi-Protocol Label Switching) network and its extended architecture GMPLS (Generalized MPLS) that supports multiple classes of switching. We used the notation MPLS/GMPLS to mean MPLS or GMPLS network. We formulate the problem as a multiobjective constrained optimization problem which is known to be NP-hard. The aim is to satisfy the requirements of emerging network applications while optimizing the network performance and the utilization of the available resources within the network. Then, we develop a hybrid heuristic algorithm based on combining linear programming and a Pareto-based genetic algorithm for approximating the optimal set of tradeoffs (also known as Pareto front or nondominated solution set) in a single simulation run. The performance of six variations of the proposed heuristic is also evaluated and compared using a numerical example adopted from the literature. We study the statistical significance of the results using Kruskal–Wallis nonparametric test (Conover, 1999). We also compare the results of the heuristic approach with the lexicographic weighted Chebyshev method (Marler and Arora, 2004) using a variety of performance metrics.

The remainder of the paper is organized as follows. Section 2 briefly reviews the related work. Section 3 describes the problem and model the multipath traffic engineering in MPLS/GMPLS based networks as a multiobjective constrained mixed-integer program. Section 4 presents the proposed hybrid evolutionary

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solution methodology. Section 5 evaluates the performance of the proposed approach and discusses the results using a numeric example from the literature. Finally, Section 6 concludes the paper and presents some ideas for future work.

2. Literature review

Providing quality of service for diverse applications and performance optimization of network operation are challenging tasks (Mahmoud et al., 2012). In this section, we provide a brief review of some related work in the literature. Various approaches have been presented in the literature including traffic engineering optimization ranging from single path to multipath routing (Wang et al., 2008). This includes enhancing Interior Gateway Protocols in traditional IP networks such as OSPF (Open Shortest Path First) or IS-IS (Intermediate System-to-Intermediate System) (Sridharan et al., 2003; Xu et al., 2011; Song et al., 2011; Islam and Oki, 2011; Kamrul and Oki, 2011). Another approach that has received considerable attention is constraint-based routing (Younis and Fahmy, 2003; Karaman, 2006; Khan and Alnuweiri, 2004) where routes are computed subject to bandwidth and administrative constraints.

With the advent of MPLS (Multiprotocol Label Switching) or its generalized version GMPLS, constraint-based routing is made more simpler (Osborne and Simha, 2002). An early simple approach repeats the application of constrained shortest path first (CSPF) routing to determine the least-cost (or shortest) paths after removing edges that violate certain constraints such as number of hops (traversed links), minimum bandwidth, or end-to-end delay. But this approach does not consider subsequent traffic requests while computing the shortest path; and hence one current allocation may lead to blocking many other traffic requests. An extension of shortest path routing protocols is equal cost multipath (ECMP) routing that allows traffic to split equally over several paths. In its general settings, the problem is characterized by the existence of conflicting objectives (e.g. customer satisfaction often conflicts with network operator's objectives), mixed-type decision variables (i.e. binary, integer and real), and multiple constraints. As mentioned by many authors, this multiobjective constrained optimization problem is NP-hard (Cho et al., 2003; Fortz and Thorup, 2000; Erbas and Mathar, 2002). Thus, even for some tens of nodes, an exact method takes long time to solve it. Therefore, it is much more appealing to develop specific or heuristic algorithms to solve this problem. A survey and analysis of the state-of-the-art of exact and approximate techniques that have been proposed to solve the multi-constrained optimal path (MCOP) problem is presented in Garroppo et al. (2010). The goal of MCOP problem is to find a route between a source–destination pair that meets various quality of service requirements, e.g. bounded delay and packet loss. Other heuristic techniques based on simulated annealing, simple genetic algorithms or NSGA-II (Deb et al., 2002) have been proposed in Erbas and Mathar (2002), Erbas and Erbas (2003), Erbas (2004), El-Alfy et al. (2007) and El-Alfy (2010). Other related work on optical networks is presented in Huang and Ma (2011), Guo et al. (2007), and Chen et al. (2008). The authors in Huang and Ma (2011) presented a framework for quality of service prediction in single-hop passive star-coupled optical network. Their framework composed of four modules that cooperate to dynamically adapt the network behavior to maintain the level of quality delivered to end users. Guo et al. (2007) presented a path provisioning approach with shared protection to tolerate the single-risk failure in optical networks. Chen et al. (2008) formulated and solved an extended multicast routing and wavelength assignment (RWA) problem that incorporates delay constraints in heterogeneous light splitting capabilities. They also presented a heuristic called near-*k*-shortest-path heuristic (NKSPH) to solve the problem in large-scale networks. Further details on the theory and performance of multiobjective evolutionary algorithms and some of their applications in networking can be found in Coello (2005), Coello et al. (2005), Zitzler et al. (2003), Zitzler and Thiele (1999), Abd-El-Barr (2009) and Abdou et al. (2011).

3. Problem description and formulation

In this section, we describe the problem and formulate it as a multiobjective constrained optimization problem. We start with a bit of background to briefly review the characteristics of MPLS/GMPLS based networks. For the detailed description of MPLS/GMPLS technology, we refer the reader to Awduche (1999), Awduche and Jabbari (2002), Xiao et al. (2000) and Meng et al. (2011). MPLS/GMPLS-enabled routers are offered by major networking vendors and are deployed in backbone networks by many ISPs (Internet Service Providers) (Osborne and Simha, 2002). Figure 1 shows a typical

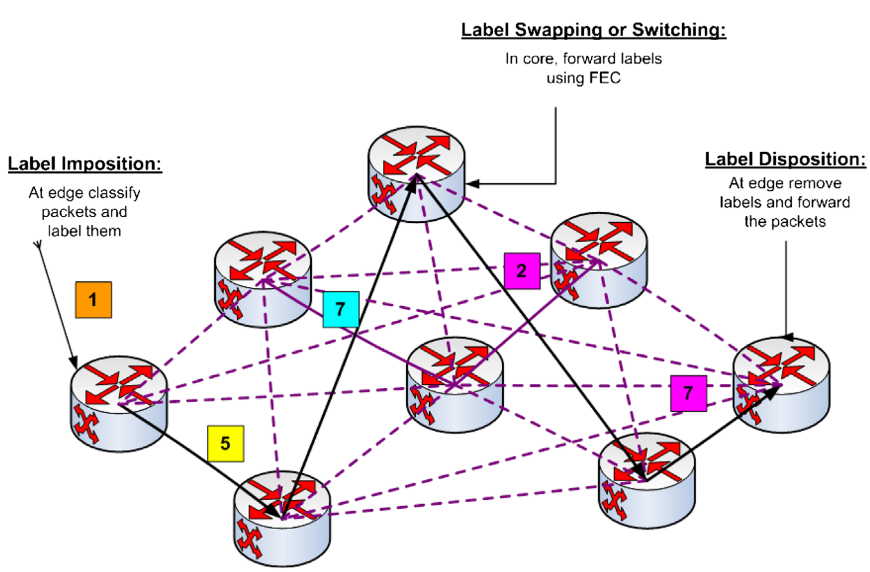

Fig. 1. Structure of a typical MPLS/GMPLS-based network.