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Robust Optimization for OSPF Routing ⋆

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Abstract: Given a weight for each network link, which is set by the network operator, the OSPF routing protocol states that the data between each pair of nodes is routed through the shortest path between the sender and the receiver. In the case of multiple shortest paths, the traffic is split evenly, among all outgoing links that belong to the shortest paths. The OSPF weight setting problem consists in assigning the link weights such that the respective shortest path routing results in the least congested network. Most of the works in the literature assume that a single static traffic matrix is available. However, the traffic on computer networks may significantly vary in different periods of time, and it is not practical for the network operator to manually change the weights of the links each time significant variation in traffic occurs. These factors motivated the development of optimization models for OSPF weight setting that deal with traffic uncertainties. Instead of minimizing the average congestion over all scenarios as is the case of the works in the literature, we propose a new optimization models, based on Robust Optimization, where the congestion in each scenario is considered individually. We argue that the user experiences each scenario individually. Therefore, a solution that is good on average may sometimes result in a bad quality-of-service from the user point of view. Computational experiments show that, compared to the approach that minimizes the average case, our approach is able to reduce the congestion regret by 24.96%, while increasing the average congestion by only 0.72%, indicating that our approach may be a better alternative for weight setting in OSPF networks.

Keywords: OSPF, Robust Optimization, Traffic Engineering, Heuristics.

1. INTRODUCTION

The Internet is a global network connecting routers, switches, and hubs that communicate mainly through the Internet Protocol (IP). The data is transmitted in small units called packets, that contain the message being sent, the destination address, as well as other relevant information. Every subnetwork that is under the administration of a single institution is called an autonomous system (AS) . The Internet can be divided into two layers of protocols: the *intra-domain* layer, implemented by the Interior Gateway Protocols (IGPs), is responsible for managing the traffic *inside* an autonomous system, while the *inter-domain* layer deals with the traffic *between* the autonomous systems.

One of the responsibilities of an AS is to solve the routing problem, that consists in deciding the paths through which the network flow is going to pass. Since there are many possible routes for each demand, deciding the path of the data is crucial to avoid link overloading, in order to achieve better response times and to keep the network reliable. There are several protocols that provide intra-domain routing, such as RIP (Hedrick, 1988), OSPF (Moy, 1989), and IS-IS (Oran, 1990). Each organization is responsible for choosing the protocol that suits best its demands. Nowadays, OSPF and IS-IS are the most common choices.

The Open Shortest Path First (OSPF) protocol is an IGP that was created by the OSPF working group of the Internet Engineering Task Force (Moy, 1989). In OSPF routing, the network administrator assigns integer weights to each link of the network. These weights are used as lengths to calculate the shortest paths between all pairs of routers, and the data is routed through these shortest paths. In the case of multiple shortest paths, the traffic is split evenly, among all outgoing links that belong to the shortest paths. This behavior is called Equal Cost Multi-Path (ECMP) rule. The quality of the routing is related to this weights assignment, and define a problem known as the weight setting problem (WSP).

The remainder of this text is organized as follows. Section 3 presents the models proposed in this work and the algorithms used to solve them. Next, the computational experiments are reported in Section 4. Concluding remarks are drawn in the last section.

2. PROBLEM DEFINITION

WSP consists in assigning the link weights in order to optimize an objective function that models some network performance metric. The problem is part of a wider area, called Traffic Engineering, responsible for managing the resources of the network to satisfy the user demands. It was proven to be NP-hard in Fortz and Thorup (2000).

WSP was modeled by Fortz and Thorup (2000) as follows. Given a directed graph $G = (N, A)$, where N is a set

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of nodes that represent the network routers, and A is a set of arcs that represent the network links. The capacity of each link $a \in A$ is denoted by $c_a \in \mathbb{N}$. Besides, d is a traffic demand matrix, where each element $d_{ij} \in \mathbb{N}$ tells how much traffic flows from $i \in N$ to $j \in N$. The decision variables $w_a \in \{1, \ldots, 65535\}$ are the weights assigned to each link $a \in A$, and the objective function aims at minimizing a function Φ that models the network congestion. Given the weight of each link $a \in A$, let l_a be the resulting amount of flow passing through arc a, and $\phi_a(l_a)$ be the monotonically increasing piecewise linear convex function that models the congestion of a, where $u_a = \frac{l_a}{c_a}$ is the utilization ratio of the link a. The Equation (1) shows the derivative $\phi'_a(l_a)$ of the function $\phi_a(l_a)$. The objective function Φ is defined as the sum of ϕ_a for all arcs $a \in A$, as shown on Equation (2). The closer is the flow of an arc to its capacity, the more expensive it is to add flow to it. We note that in this model the amount of flow l_a of the arc $a \in A$ can be larger than its capacity c_a. However, in this case the congestion cost of a is very large.

$$\phi'_a(l_a) = \begin{cases} 1 \; for & 0 \leq \frac{l_a}{c_a} < 1/3 \\ 3 \; for & 1/3 \leq \frac{l_a}{c_a} < 2/3 \\ 10 \; for & 2/3 \leq \frac{l_a}{c_a} < 9/10 \\ 70 \; for & 9/10 \leq \frac{l_a}{c_a} < 1 \\ 500 \; for & 1 \leq \frac{l_a}{c_a} < 11/10 \\ 5000 \; for & 11/10 \leq \frac{l_a}{c_a} \end{cases} \quad (1)$$

$$\Phi = \sum_{a \in A} \phi_a(l_a) \quad (2)$$

There are several objective functions that can be used for Traffic Engineering. Balon et al. (2006) compared and evaluated nine objective functions found in the literature. They concluded that despite each objective have its own pros and cons, the objective function used by Fortz and Thorup (2000) performs well in all scenarios. Therefore, in this work we focus on the problem as modeled by Fortz and Thorup (2000), in which the function Φ is used as the objective function.

Several works assume that a single static demand matrix is available (Fortz and Thorup, 2000; Pióro et al., 2002; Ericsson et al., 2002; Buriol et al., 2005; Reis et al., 2011). However, the traffic on computer networks may significantly vary in different periods of time. Unfortunately, it is not practical for the network operator to manually change the weights of the links each time a significant variation in traffic occurs, because this might disrupt the consistency and dependability of network operations. These factors motivated the development of models for OSPF weight setting that deal with traffic uncertainties (Fortz and Thorup, 2002; Mulyana and Killat, 2005; Abrahamsson and Bjorkman, 2009; Altın et al., 2010; Altin et al., 2012).

The works Fortz and Thorup (2002) and Altin et al. (2012) assume that the uncertainty in the network traffic can be approximated by a set R of demand matrices, with each matrix representing a possible scenario of traffic. Given a solution with the weight of each link $a \in A$, let Φ_r be the cost of Φ for the demand matrix $r \in R$. The objective function used in these works consists in minimizing the sum of Φ_r for all demand matrices in R, i.e. $\Phi^S = \min \sum_{r \in R} \Phi_r$. This is equivalent to minimize the average of Φ_r, for all $r \in R$, as the number of matrices in R is fixed.

In this work, we propose a new approach for the OSPF weight setting problem that also uses a set of demand matrices (traffic scenarios) to model the uncertainty in the network traffic. However, instead of minimizing the average value of Φ_r, as is the case of Altin et al. (2012) and Fortz and Thorup (2002), in our approach each scenario is considered individually. We argue that, the user experiences each scenario individually. Therefore, a solution that is good on average may sometimes result in a bad quality-of-service from the user point of view, during some of the scenarios.

We propose a new optimization model for weight setting in OSPF networks based on Robust Optimization. We propose a *minmax regret* model that minimize, for each scenario, the regret of using the given weight setting, instead of the optimal weight setting, for that scenario. As finding the cost of the optimal weight setting for one scenario is NP-Hard, our approach uses the well known lower bound to this cost proposed in Fortz and Thorup (2000). As far as we know, this is the first work in the literature that uses this approach in order to deal with the OSPF weight setting problem.

To solve the proposed model, we extend, evaluate, and compare the best algorithms for the OSPF weight setting problem in the literature. The first algorithm is the tabu search of Fortz and Thorup (2000), and the second is the genetic algorithm of Buriol et al. (2005). Both approaches are extended for our proposed model. Computational experiments, performed on realistic and artificial instances, show that our approach is able to reduce the congestion regret of Fortz and Thorup (2002) by 24.96%, while increasing the average congestion by only 0.72%, indicating that our approach may be a better alternative for weight setting in OSPF networks.

3. ROBUST OPTIMIZATION APPROACH

In this Section, we propose a robust optimization model for the OSPF weight setting problem. Here, the term Robust Optimization (RO) refers to the framework discussed in Kouvelis and Yu (1997). Thus, it can not be confused with robustness to link failures, and polyhedral demand uncertainty.

Robust Optimization (Kouvelis and Yu, 1997) is a way to deal with uncertainty in decision making, where the variability of the data is represented by deterministic values. It is specially useful when the decision maker is interested on the outcome of all potential scenarios, and not only the expected or the most likely to happen. This situation is common when the decision has to be made once, and cannot be changed easily, or when the decision maker does not want to assume the risk of underperforming for some scenarios.

The OSPF weight setting problem fits into both categories. The weights cannot be changed frequently, as it can disrupt the consistency and dependability of the network. Furthermore, it may not be interesting for the network