New advances in Segment Routing optimisation

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The internet is composed of a set of autonomous systems (AS). An autonomous system is a set of routers under a single technical administration such as an internet service provider (ISP). To this day the internet still relies on packet switching. Transferred data is broken down into packets for more efficient transfer. The goal at the network layer of the internet is to provide the way to transport datagrams (IP packets), from their source to their destination.

The paths to follow are chosen by the internet routing protocols. These can be divided into two main groups : inter-domain and intra-domain routing protocols, also called respectively border gateway protocols (BGP) and interior gateway protocols (IGP). As their names indicate, BGPs are used to handle traffic between ASes and IGPs handle routing within ASes [1].

The branch that aims to improve the quality of service for IGP protocols is called Traffic Engineering (TE). From an optimisation point of view, the aim is to send each packet using the most efficient route across the network at that time by (re-)optimising the routing of the traffic, but leaving the network topology and hardware configuration unchanged [3].

One of the most important problems TE has to deal with is network congestion, because it almost always results in degradation of user experience. Network congestion occurs when the network has to carry more data than what it can handle. Usually TE techniques try to minimise the maximum link utilisation where the link utilisation is define as the total flow on the link divided by its capacity.

The most widely used IGP protocols rely on shortest path routing (SPR) : traffic flowing from one router to another will always be routed along the shortest path. The shortest paths are computed using a link metric system, a weight is assigned to each link and these weights are used to determine the shortest path from one node to another. In case multiple shortest paths exist, a usual rule is to split traffic evenly on all outgoing arcs belonging to a shortest path. This technique is called *Equal Cost Multi-Path* (ECMP).

A lot of research have been devoted to TE with SPR protocols, see [1, 4, 6] for surveys on the topic.

Even when optimized, SPR protocols suffer a number of drawbacks. Demand matrices and networks change. As described in [7], operators do not like to change weights, because it can lead into transient instability until the distributed computation of the shortest paths converges. Moreover, SPR might be very far from an optimal routing where flow can be distributed freely in the network [8].

To provide more flexibility in routing and decrease the overhead induced by SPF protocols, Segment Routing (SR) was recently introduced. SR is a modern variant of source routing in computer networks, which is being developed within the SPRING and IPv6 working groups of the IETF [5, 10]. In a segment routed network, an ingress node may prepend a header to packets that contain a list of segments, which are instructions that are executed on subsequent nodes in the network. These instructions may be forwarding instructions, such as an instruction to forward a packet to a specific destination or interface. These instructions act on top of an existing protocol, like SPF ones. More precisely, an instruction to forward a packet to a specific router to reach a destination will be performed using the underlying protocol.

Here, we assume that routing in the underlying protocol, e.g. SPR with ECMP, is given, i.e. the link metric system is fixed and cannot be modified. We consider the problem of routing given demand matrix using node segments (i.e allowing to fix a set of nodes to visit to reach a destination from a given origin), with a given upper bound K on the number of segments used. For $K = 2$, the problem was formulated as a compact MIP in [2]. For $K \geq 2$, a compact MIP formulation was proposed in [9], but with a very poor linear relaxation. A path-based formulation was proposed in [11] and solved with a column-generation based heuristic.

In this talk, we introduce the notion of *forward graph* and extend it in the context of SR. We study theoretical properties of forward graphs and derive a pre-processing technique allowing to eliminate more than 90 % of the paths on realistic instances. These pre-processing techniques are made very efficient by the use of adequate data structures to represent the forward graphs. We also show with an extensive set of numerical experiments that the pre-processed models can be solved by state-of-the-art solvers without the help of column generation.

In future research, we plan to consider the simultaneaous optimization of SPR metrics and SR paths, and to consider uncertain demand matrices.

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