Lagrangian relaxation for the design of virtual IGP topologies

Nicolas Huin[2], Jérémie Leguay[1], Sébastien Martin[1], Zhengdegao[1]

[1] Huawei Technologies & co. 20 Quai du Point du Jour, Boulogne Billancourt, France
{jeremie.leguay,sebastien.martin,zhengdegao}@huawei.com

[2] IMT Atlantique/IRISA/Adopnet, France nicolas.huin@imt-atlantique.fr

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1 Introduction

Due to the advent of 5G, networks need to support a wide variety of Quality of Service (QoS) constraints while current equipment and protocols mostly offer best-effort routing. Operators are reluctant to switch to a fully centralized control plane to decide routing and they are more interested in solutions that extend the protocols they are using today.

Large-scale telecommunication networks rely on Interior Gateway Protocols (IGP), such as the Open Shortest Path First (OSPF) protocol [2], to build and maintain a single shortest path tree for each router. Using Link State Advertisements (LSA), OSPF distributes the network's state to each router, which then computes a shortest-path tree towards other equipment. Routers use this tree to determine the next hop on which packets are forwarded. The weights given to the links heavily influence the shape of the shortest-path tree.

To increase routing options, to support different application needs, or to better load balance traffic in the network, an extension of IGP called Multi-Topology Routing (MTR) has been proposed. It runs multiple IGP instances in parallel, each of them working with a different set of link weights and maintaining a Shortest-Path Tree (SPT). Each SPT, also called a topology, relates to different routing criteria (e.g., cost, hop, delay). As routers execute multiple IGP instances, each instance advertises its link states. In practice, if the number of topologies is large, it may lead to a huge protocol overhead. It can be the case when a heterogeneous set of QoS requirements must be satisfied.

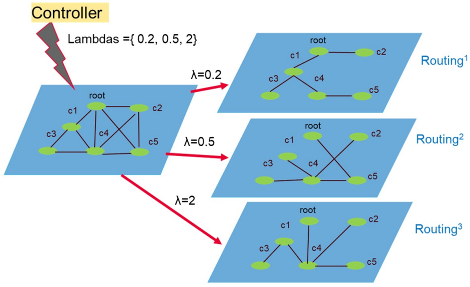
The design and update of OSPF weights is no easy feat. On the one hand, operators can design the weights with the famous rule of thumb that aims at funneling the traffic on the highest bandwidth links — by setting the weight of a link to $\frac{10^8}{\text{BW}}$, where BW is the bandwidth of the link. However, this rule ignores QoS constraints. On the other hand, operators can design the weights such that the resulting shortest-path trees respect the QoS constraints given as an input. Known as the Inverse Shortest Path problem, this problem is a well-studied NP-hard problem [3]. Moreover, paths changes floods the network with LSA messages for the new link weights and incapacitate the network during OSPF's convergence.

We present a new system architecture that extends MTR to build several virtual topologies on top of existing (real) ones. The main goal is to reduce the protocol overhead that may occur with a large number of topologies and to accommodate a large set of demands with heterogeneous QoS requirements. Instead of designing link weights for different topologies, our system derives virtual topologies from real ones (e.g., cost, latency) using Lagrangian relaxation. In this case, only Lagrangian multipliers are communicated by the network management system to routers, one per real topology which drastically reduces overhead. In addition the virtual topologies that are created are "silent", i.e., they do not exchange additional LSA messages.

2 Virtual IGP topologies

2.1 System architecture

In the Virtual IGP (vIGP) architecture we propose, the network management system (the controller) communicates Lagrangian multipliers, called lambdas, to routers so that they can compute virtual topologies based on the set of existing physical topologies. This solution allows combining real topologies that are typically associated with different administrative or QoS metrics (e.g., cost, latency, loss).



Virtual topologies in an IGP.

For instance, if we consider two real topologies T_d where the weight is equal to the link latency and T_l where the weight is equal to the log of packet loss probability, then the controller can communicate to routers a lambda multiplier to obtain a trade-off between latency and packet loss. Considering a $\lambda = 0.5$ implies a new weight

$$T_{\lambda=0.5} = T_d + 0.5T_l.$$

This mechanism can be seen as a Lagrangian relaxation where each QoS constraint is relaxed and added to the objective function.

Each device can compute the Dijkstra tree T_λ without exchanging LSA to update the weight of all links in the network using only one lambda. The gain of LSA and thus of bandwidth overhead is really important. Furthermore, we can modify quickly the lambda with limited convergence issue.

2.2 Selection of lambdas

From the operational research point of view, the problem is to find the minimum number of lambdas such that all demands in the network respect their QoS requirements. Indeed, even if virtual topologies reduce considerably the bandwidth overhead and convergence issue, each router must maintain a routing table for each virtual topology. For this reason, the goal is to minimize the number of virtual topologies. We provide a polynomial algorithm based on LARAC [1] algorithm to solve this problem.

3 Conclusion

In this paper, we present the vIGP architecture using an idea coming from Lagrangian relaxation to face heterogeneous QoS requirements in MTR. We propose an algorithm based on Lagrangian relaxation to select a minimum set of lambdas.

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