Model-independent routing for low latency

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1 Introduction

5G promises to improve network performance in the way of delay, bandwidth or scalability : an increasing number of services can be moved to the cloud and the edge, putting the computation burden of services such as video game streaming, V2X or AI assistant away from the customers. But these types of services requires stricter Quality of Service (QoS) constraints (e.g., delay, losses, jitter) and satisfying them is crucial.

Modeling the delay from the queuing system is a well studied problem but only few works have tackled it from as a global optimization problem. Fortz *et al* considered the piecewise linear unsplittable multicommodity flow problem [2] : we generalize their model by considering other delay models. Ben Ameur *et al* [1] considered the Kleinrock function [3] and gave a convex relaxation to compute a lower bound of the (fractional) routing problem with minimum linear cost. Truffot *et al* [4] proposed a linear relaxation of a non-linear and non-convex problem, formulated also using the Kleinrock function, to minimize the maximum end-to-end latency. They solved the integer problem using a branch-and-price algorithm.

In this paper, we focus on using more realistic model of delay, which includes different classes of traffics that are sent with different priorities. We use a decomposition based on column generation for solving the multi-commodity flow problem when the delay is not constant (called Variable Delay Multi-commodity flow problem).

2 Problem statement and model

Let $G = (V, E)$ be a graph representing the network. Each link $e \in E$ is characterized by its propagation delay (d_e) and its bandwidth capacity (c_e). Let K be the set of requests to provision on the network. Each demand $k \in K$ is characterized by its source (s_k), its destination (t_k), its bandwidth requirement (b_k) and its delay requirement (d_k).

The goal of the Variable Delay Multi-Commodity Flow (VD-MCF) problem is to maximize the number of requests provisioned, respecting the link capacity constraints and requests delay constraints.

For each link $e \in E$ and each demand set $K' \subseteq K$ we consider a binary variable $x_e^{K'}$ equals to 1 if the demands in K' use the link $e \in E$ and 0 otherwise. We also consider for each demand $k \in K$, for each path $p \in P_k$ which links nodes s_k nd t_k in G and for each subset $K' \subseteq K$ a binary variable $y_p^{K'}$ equals to 1 if the set of demand K' traverses the path p and 0 otherwise. $\delta_e^{c(k)}(K')$ corresponds to the delay of demand $k \in K'$ (belonging to class c traffic) on e when e is processing the demands in K'.

The following integer linear program solves the Variable Delay Multi-commodity flow problem.

$$\begin{aligned}
\max \quad & \sum_{k\in K}\sum_{p\in P_k} y_p^k \\
\gamma_k: \quad & \sum_{p\in P_k} y_p^k \le 1 && \forall k\in K \\
\alpha_{ke}: \quad & \sum_{p\in P_k: e\in p} y_p^k - \sum_{K'\subseteq K: k\in K'} x_e^{K'} \le 0 && \forall k\in K, \forall e\in E \\
\alpha_e: \quad & \sum_{k\in K}\sum_{p\in P_k: e\in p} b_k y_p^k \le c_e && \forall e\in E \\
\beta_k: \quad & \sum_{e\in E}\sum_{K'\subseteq K: k\in K'} \delta_e^{c(k)}(K') x_e^{K'} \le d_k && \forall k\in K, \\
\beta_e: \quad & \sum_{K'\subseteq K} x_e^{K'} \le 1 && \forall e\in E \\
& x_e^{K'} \in \{0,1\}
\end{aligned}$$

Inequalities α^{ke} ensure that if a path p is used by demand k then at least one subset K' containing k is activated on e. Inequalities α_{ke} are the flow constraints for demand k. Inequalities α_e are the capacity constraints. Inequalities β_e guarantee that only one subset of demands is activated for each node. Inequalities γ_k guarantee that only one path is activated for each demand. Inequalities β_k are delay constraints.

Variables $x_e^{K'}$ and y_p^k are in exponential number thus it is necessary to generate them using column generation procedure.

The pricing problem associated with x_p consists in finding a shortest path problem (classic column generation MCF).

The pricing problem associated with the variables $x_e^{K'}$ for a given edge e consists in finding the subset K^* of K which maximizes the reduced cost $\sum_{k\in K^*} \alpha_{e,k} - \sum_{k\in K^*} d_e^{K^* c(k)} \alpha_k^2 - \alpha_e$. Furthermore, the set of admissible subsets, say $\mathcal{K}$, is defined by the knapsack constraint $\forall K' \in \mathcal{K}, \sum_{k\in K'} b_k \le C_e$.

3 Conclusion

We present a new decomposition model for solving the Variable Delay Multi-commodity Flow (VD-MCF) problem. The strength of the model comes from the fact that we can plug any kind of delay model in the pricing problem : from a simple M/M/1 queuing system to more complex system, where the delay evaluation could be done using machine learning algorithm.

Références

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