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1 Introduction

With the tremendous growth of Internet traffic, the network energy consumption is inherently growing fast with a rate of 10% per year, which exceeded 350 TWh and represented 1.8% of the worldwide electricity consumption in 2012. It is even reported that communication networks will consume as much as 51% of the global electricity in the worst case by 2030 if its energy efficiency is not improved enough. Thus, the problem of energy efficiency is becoming critical for nowadays communication networks.

To reduce energy consumption, green networking has attracted a lot of attention from device manufacturers and Internet Service Providers (ISP). In the literature, energy-aware traffic engineering problem is proposed to minimize the total energy consumption by switching off unused network devices (routers and links) while guaranteeing full network connectivity [1, 2].

In this work, we are interested in the problem of energy-aware Traffic Engineering (TE) while using multipath routing to minimize link capacity utilization in ISP backbone networks.

2 Problem description

We consider the ISP backbone network modeled by the bi-directed graph $G(V, A)$, where V is the set of routers and A represents the set of communication links.

Let $C_{ij} \geq 0$ denotes the capacity of the link $(i, j) \in A$, and K be the set of traffic demands, where $(s, t) \in K$ is the demand between node s and node t. We denote by P_i the energy consumption of the chassis in router i, and we use g_{ij} to represent the energy efficiency of the line cards connecting the link (i, j).

The optimizaton problem we study selects a set of routers (nodes) and links (arcs) to be activated with minimum energy consumption. In addition, each traffic demand has to use a multipath flow minimizing the total link capacity utilization.

The problem is naturally cast as a bi-level optimization problem where the upper level represents the energy management function and the lower level refers to the deployed multipath routing protocol. For each $i \in V$ and $(i, j) \in A$, we introduce the binary variables z_i and y_{ij} that represent the power status (ON/OFF) of the router i and the link (i, j), respectively. Furthermore, let the positive variable x_{ij}^k be the flow on (i, j) of the demand k. A bi-level MILP formulation of the problem is given by:

$$\min \quad \sum_{i \in V} P_i z_i + \sum_{k \in K} \sum_{(i,j) \in A} g_{ij} x_{ij}^k \tag{1a}$$

$$\text{s.t.} \quad z_i, y_e \in \{0, 1\} \qquad\qquad \forall i \in V, \quad \forall e \in E, \tag{1b}$$

$$y_e \geq z_i + z_j - 1, \quad y_e \leq z_i, \quad y_e \leq z_j \qquad \forall e = \{i, j\} \in E, \tag{1c}$$

$$\min \quad \sum_{k \in K} \sum_{(i,j) \in A} x_{ij}^k \tag{1d}$$

$$\text{s.t.} \quad \sum_{(i,j) \in \delta^+(i)} x_{ij}^k - \sum_{(i,j) \in \delta^-(i)} x_{ji}^k = b_i^k \qquad \forall i \in V, \forall k \in K \tag{1e}$$

$$\sum_{k \in K} x_{ij}^k \leq C_{ij} y_e \qquad\qquad \forall (i, j) \in A \tag{1f}$$

$$x_{ij}^k \geq 0 \qquad\qquad \forall (i, j) \in A, \forall k \in K, \tag{1g}$$

The upper level objective function (1a) minimizes the energy consumption of routers and links, while the objective of the second level problem minimizes the total link capacity utilization (1d). Constraints (1c) ensure that a link (i, j) is activated only if the two routers i and j are switched ON. Constraints (1e) and (1f) define the classical flow and capacity constraints, respectively.

We solve the above problem exactly by reformulating it as a MILP using three different types of optimality conditions:

- KKT optimality conditions,

- Residual network optimality conditions,

- Inequalities eliminating suboptimal flows.

3 Computational experiments

We compare the three approaches numerically on different network topologies provided by [3], Polska, Geant and Abilene networks. The two first sets of constraints are used to solve the problem by plain "Branch-and-Bound" algorithms. In addition, an iterative cutting plane and branch-and-cut algorithms are implemented using the inequalities that eliminate unfeasible flows. For all these instances, we found that the iterative cutting plane and branch-and-cut algorithms outperform the branch-and-bound algorithm using KKT and residual network optimality conditions.

References

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