Energy-Efficient Traffic Engineering for Future Networking Infrastructures

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Abstract

A general problem formulation for energy-efficient traffic engineering for future core networks is presented. Moreover, a distributed heuristic algorithm that provides jointly load balancing and energy efficiency is proposed. Simulation results show that the proposed algorithm approaches the optimal network operation, in terms of throughput and energy consumption.

Keywords: Network Management, Traffic Engineering, Load Balancing, Energy-awareness.

1 Introduction

While the networked communication systems are continually evolving, network and service management is crucial to ensure proper operation (as far as configuration, performance, faults, security issues and accounting are concerned). Nowadays, expert human resources and complex systems are required to manage the increasing plethora of networked devices, ranging from small sensors to terabit routers, and the large variety of applications. The explosion of the Internet and the proliferation of networked devices create unique challenges for network and system management. Moreover, the complexity of networked systems and the cost of management are also constantly growing. Therefore, novel traffic engineering solutions are needed in order to guarantee the efficient operation of the next generation networks.

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Traffic Engineering (TE) plays a crucial role in determining the performance and reliability of network deployments. A major challenge in traffic engineering is how to cope with dynamic and unpredictable changes in traffic demands and how the network could handle possible traffic variations in a way that *load balancing*, *congestion avoidance* and *efficient service provisioning* are ensured. In this direction, *TE* approaches must apply efficient resource optimization strategies so as to eliminate these effects. A more straightforward explanation of *TE* is given in [1]: *"to put the traffic where the network bandwidth is available"*. Therefore, the nature of *TE* is effectively a kind of routing optimization for enhancing network service capability to achieve the aforementioned objectives.

Recently, there is an increasing interest in providing *energy-aware* network operation. The rapid growing of the users and the services that must be supported, the spreading of broadband access in conjunction with the increased energy prices affected the demand for energy-aware service provisioning. Unfortunately, the current underlying network infrastructures, namely routers, switches and other network devices, lack effective energy management solutions.

In this paper we provide a joint problem formulation for optimal energy-aware load balancing in the network. Then, we propose a distributed *ENergy-Aware TRaffic Engineering (ENTRE)* scheme that smoothly introduces the aforementioned major issues in real network deployments.

2 Related Work

Traffic Engineering is a widely studied topic in literature. Fortz et al. were the first to propose the idea of IGP link weight optimization [2], [3]. Several other representative approaches could be classified into the following categories: Intradomain and Interdomain [4], MPLS-based and IP-based [5], [6], Offline and Online [7], [8], Unicast and Multicast [9], [10].

A challenging task is to identify the main parts of the Internet that dominate its power consumption and investigate methods for improving energy consumption [11]. The first attempt to introduce energy savings in the Internet was made in [10]. Moreover, several approaches studied the problem of managing energy consumption in end user devices [12] and LANs [13], [14].

Recently, the authors in [15] discuss the idea of dynamically turning part of the network operations into sleeping mode, during light utilization periods, in order to minimize the energy consumption. The authors in [16] identified the power saving problem in the Internet, and propose sleeping as the approach to conserve energy. In their approach they support uncoordinated sleeping which works at link level and coordinated sleeping which operates at network level. Moreover, routing, rate adaptation and network control are mobilized towards energy-efficient network operation [17–19], [26], [27].

Chabarek at al. [20] introduced power awareness in network design and routing and they conduct valuable experiments with popular routers and create a router power consumption model.

Lastly the authors in [21] propose an intra-domain traffic engineering mechanism, which maximizes the number of links that can be put into sleep under given performance constraints such as link utilization and packet delay.

Unfortunately, none of these approaches provide problem formulation in the direction of jointly studying the "traditional" objectives and the new objectives (energy-awareness) of *TE*. This paper is an attempt to put these objectives under a joint problem formulation and to propose lightweight solutions that could be applied in real network deployments.

3 Traffic Engineering Approach

In this section we give a general formulation of the joint load balancing and the energy efficiency problems. Then, we present a distributed *ENergy-Aware TRaffic Engineering (ENTRE)* scheme that follows the guidelines provided by analysis of the joint problem formulation.

3.1 Network Model

Figure 2.1 depicts our network model, where each ingress router may have traffic demands for a particular egress router or set of routers. Multiple paths (MPLS tunnels) are used to deliver traffic from the ingress to the egress routers. Traffic is split among the available paths at the granularity of a flow, to avoid reordering TCP packets or similar effects that lead to performance degradation (using efficient traffic splitting approaches, like [22]). Moreover, we consider that the paths are computed and re-computed (if it is necessary) offline by the operator, since most of the operator's networks work in this way.

Formally, we assume that for each ingress-egress node pair i the traffic demand is T_i and multiple paths P_i could be used to deliver the traffic from the ingress to the egress node. Therefore, a fraction of the traffic x_{ip} is routed along path $p(p \in P_i)$. In addition, the energy consumption of an active link is affected by the maximum rate that the link can support (10Mbps, 100Mbps, etc) and

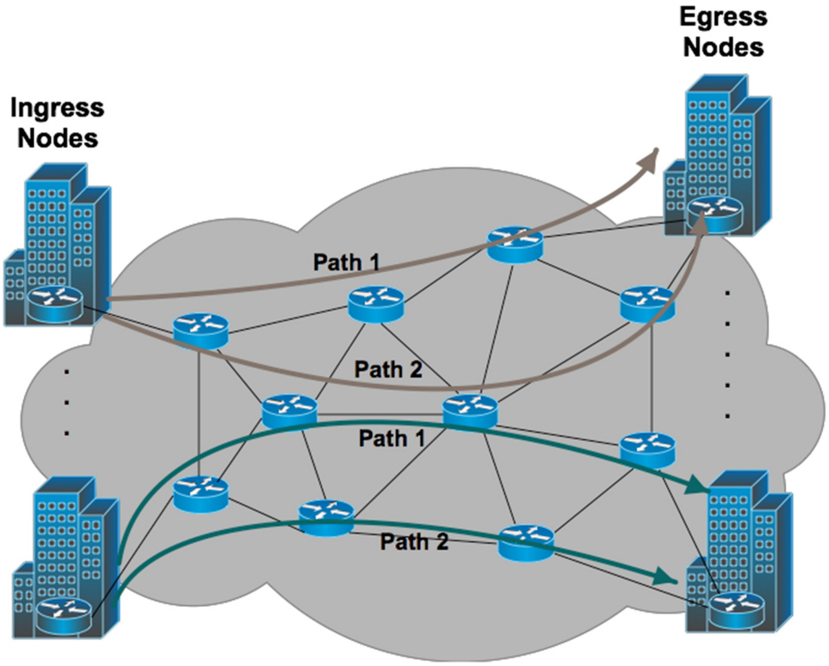

Figure 1 Network topology

the current utilization of that link. The calculation of the energy consumption of link l, e_l, with capacity c_l, is based on the simple model proposed in [23] (used also in several approaches in literature):

$$e_l = PowerConsumption(c_l) \times UtilizationFactor(l)$$

PowerConsuption(c_l) is the base power consumption of a link with capacity c_l *and UtilizationFactor(l)* is the scaling factor to account for the utilization of link l. Table I contains the definition of the variables used in our problem formulation.

3.2 Joint Problem Formulation

In our formulation, the optimal splitting of the traffic of each ingress-egress node pair along the available paths is performed with the objective: *Assure that the maximum link utilization (total traffic on an active link divided by the link capacity) in the network is minimized. In this way resource-efficient*

Table 1 Variables

Variables	Description
L	Set of links in the network
IE	Set of Ingress to Egress node pairs
e_l	Energy consumption of the port connected to link l
P_i	Set of paths of Ingress to Egress node pair i
T_i	Traffic demand of Ingress to Egress node pair i
u_l	Utilization of link l
c_l	Capacity of link l
x_{ip}	Fraction of traffic of Ingress to Egress node pair i, sent through the path p
r_{ip}	Traffic of Ingress to Egress node pair i, sent through path p
P_l	Set of paths that go through link l
L_i	Set of links that are crossed by the set of paths P_i
B_{pt_m}	Number of bits sent along the path p during t$_m$seconds

(in this case link utilization/bandwidth) and balanced/stable network operation is achieved [24]).

However, in the previous policy there are no guarantees related to the energy consumption in the network. In order to introduce energy-awareness we raise a second objective: *"Assure that the energy consumption of the active routes is balanced in the network. That is, find the route with maximum energy consumption and minimize it. In this way, resource-efficient (in this case energy consumption) and balanced/stable network operation is achieved [24]"*

In our try to avoid *"Resource Gluttony"* (in terms of bandwidth and energy) we combine the previous single objectives in a unified objective function that takes into account the link utilization and the energy consumption of the route(s) that the link belong(s) to:

$$\min_{x_{ip}} \max_{l \in L_p} \sum_{i \in IE} \sum_{p \in P_i} \left(\frac{x_{ip} T_i}{c_l} \times \sum_{k \in L_p} e_k \right),$$

$$subject\ to:$$

$$\mathrm{x_{ip}} \geq 0, \forall \mathrm{p} \in \mathrm{P_i}, \forall \mathrm{i} \in \mathrm{IE}$$
$$c_l \geq \sum_{i \in IE} \sum_{p \in P_l} \mathrm{x_{ip} T_i}, \forall \mathrm{l} \in \mathrm{L}$$
$$\sum_{p \in P_i} \mathrm{x_{ip}} = 1, \forall \mathrm{i} \in \mathrm{IE}$$
$$\mathrm{x_{ip}} = [0, 1], \forall \mathrm{p} \in \mathrm{P_i}, \forall \mathrm{i} \in \mathrm{IE}$$

The previous constraints ensure that: the fraction of traffic for a specific ingress-egress node pair sent across a path cannot be negative, the capacity of each link cannot be outreached and the traffic splitting through the available paths meets the traffic demands.

3.3 Energy-Aware Traffic Engineering (ENTRE) Heuristic

We now present an *ENergy-Aware TRaffic Engineering (ENTRE)* heuristic that follows the previous model and applies an online distributed *Traffic Engineering* approach that jointly balances load and energy consumption in realtime, responding to actual traffic demands. *ENTRE* uses multiple paths to deliver traffic from an ingress to an egress node, moving traffic from over-utilized to under-utilized paths. In these adaptive actions we take into account the energy consumption of the multiple routes. Consequently, the main contribution of our approach is to provide dynamic and lightweight management of the load and the energy consumption, avoiding in this way "resource gluttony" in the network.

In our algorithm, each ingress-egress node pair i measures every t_m seconds a change in the fraction of traffic ($\Delta\ x_{ip}$) sent along path p. Furthermore, *ENTRE* measures the energy "distance" (ΔE_{ip}) of path p from the average energy consumption of the paths between ingress-egress node pair i:

$$\Delta x_{ip} = \left(\overline{U}_i - U_{ip}\right) \frac{r_{ip}}{\sum\limits_{k \in P_i} r_{ik}}, \quad when \quad U_{ip} > U_{\min}$$

$$\Delta E_{ip} = \left(\overline{E}_i - E_{ip}\right), \quad when \quad E_{ip} > E_{\min}$$

where:

$$r_{ip} = \frac{B_{ptm}}{t_m}, \forall p \in P_i, \forall i \in IE$$

$$\overline{U}_i = \frac{\sum\limits_{p \in P_i} r_{ip} U_{ip}}{\sum\limits_{k \in P_i} r_{ik}}, \forall p \in P_i, \forall i \in IE$$

$$\overline{E}_i = \frac{\sum\limits_{p \in P_i} r_{ip} E_{ip}}{\sum\limits_{k \in P_i} r_{ik}}, \forall p \in P_i, \forall i \in IE$$

In case that $\Delta x_{ip} > 0$ (p is underutilized), the fraction of traffic sent along path p must be increased by Δx_{ip}. Contrary, in case that $\Delta x_{ip} < 0$ (p is over-utilized), the fraction of traffic sent along path p must be decreased by Δx_{ip}. It is obvious that a possible increase in the fraction of traffic sent along a path will lead to energy consumption increase (the increased maximum utilization of that path will affect the energy consumption). Since one of the main objectives of our energy-aware approach is to keep also the maximum energy consumption in low levels, we apply the same policy for the energy consumption of the paths ($\Delta E_{ip} > 0$: Energy consumption could be increased in p, $\Delta E_{ip} < 0$: Energy consumption must be decreased in p). *ENTRE* combines the previous policies, balances the traffic every t_m seconds and jointly keeps the maximum link utilization and the path energy consumption as low as possible. We summarize the basic rules in our heuristic mechanism:

1. ***IF***: $\Delta x_{ip} > 0$ and $\Delta E_{ip} > 0$ ***DO***: Apply Δx_{ip} to p
2. ***IF***: $\Delta x_{ip} < 0$ and $\Delta E_{ip} < 0$ ***DO***: Apply Δx_{ip} to p
3. ***IF***: $\Delta x_{ip} > 0$ and $\Delta E_{ip} < 0$
    a. ***IF***: $\overline{E}_i - E_{ip} > T_E$ ***DO***: Exclude p from the routing table and turn the corresponding links into sleeping mode. Traffic is proportionally provisioned to the remaining paths.
    b. ***ELSE DO***: Nothing
4. ***IF***: $\Delta x_{ip} < 0$ and $\Delta E_{ip} > 0$
    a. ***IF***: $\overline{U}_i - U_{ip} > T_U$ ***DO***: Apply Δx_{ip} to p
    b. ***ELSE DO***: Nothing

It is true that paths with higher minimum capacity need more traffic to achieve the same utilization as smaller capacity paths. This is the main reason why Δx_{ip} is normalized by the rates. This makes the change in a path's traffic proportional to its current traffic share. Lastly, we would like to note that in the execution of *ENTRE* the constraints described in the previous subsection (in the joint problem formulation) must be respected.

3.4 Implementation of ENTRE in Real Network Infrastructures

In order to give a thorough presentation of the proposed mechanism we discuss several deployment issues that arise when trying to apply the ENTRE scheme in real network deployments. Firstly, ENTRE is executed at each *IE* node pair in the network and the main decision mechanism is executed at the ingress nodes. Moreover, supposing that we support MPLS-based operation, we require several LSPs for each *IE* node pair in order to split the traffic to the available routes (the current ISP-class routers can support up to 16 LSPs). Traffic splitting is performed seamlessly using sophisticated mechanisms [14]. In addition, for each *IE* node pair MPLS-based monitoring is performed (probe request/response) in order to estimate the network and flow performance. Lastly, ENTRE is implemented on top of the router functionality (software package) handling the basic functionalities that are offered (sleeping mode, etc.).

4 Evaluation

We present the evaluation study of the proposed heuristic scheme compared to the optimal solutions. We consider a network topology where four ingress nodes send traffic to four egress nodes (20 routers in total). We are using OMNET++ to simulate *ENTRE* and IBM ILOGCPLEX Optimizer to find the optimal solutions. Figure 2.2a depicts the network throughput while the number of disjoint paths grows and Figure 2.2b depicts the energy consumption while the achieved network throughput grows (*ENTRE* is compared to OSPF [[1]]). Lastly, Table 2 presents the performance of *ENTRE*, in different scenarios, compared to the optimal energy saving in the network.

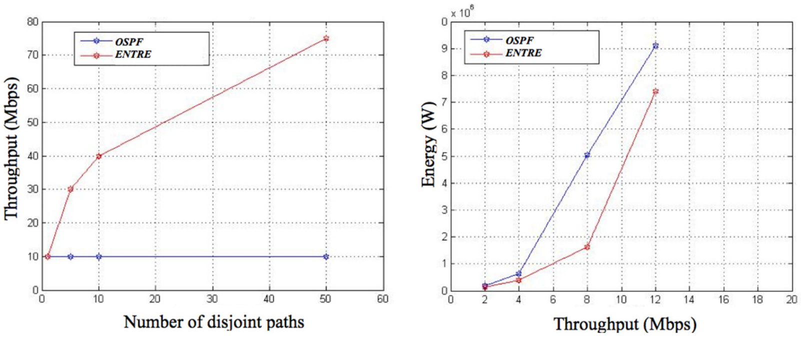

Figure 2 Network throughput and energy consumption. a Throughput (OSPF vs. our approach) and b Energy consumption (OSPF vs. our approach).

Table 2 Entre performace

Optimal Energy Saving	ENTRE Energy Saving	Percentage of “Sleeping” Links	Percentage of Routes Excluded	Average Iterations till Convergence
15%	13%	11%	7%	4
26%	23%	24%	18%	7
34%	30%	29%	24%	9
43%	38%	41%	31%	12
59%	52%	54%	41%	15

5 Conclusions

The joint modeling of balanced and energy-efficient network operation inspired the design of a heuristic approach that tries to meet the requirements of the future core networks. The simulation results show that the proposed approach tends to behave like an optimal load balancer in the network, influenced by the minimization of the energy consumption. *ENTRE* converges after a small number of iterations, proving in this way it's lightweight operation.

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Biography

George Athanasiou received the diploma in Electrical and Computer Engineering from University of Thessaly, Greece in 2005. He obtained his M.Sc. and Ph.D. degrees in Electrical and Computer Engineering from the same University, in 2007 and 2010 respectively. Currently, he is a research scientist at KTH Royal Institute of Technology, Electrical Engineering School and ACCESS Linnaeus Center, Department of Automatic Control, Stockholm, Sweden. He is also co-founder and CIO of

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