Introducing Energy-Awareness in Traffic Engineering for Future Networks

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Abstract— **One of the main challenges in the Future Internet era will be the increase of QoS-demanding applications that need to be supported. Unavoidably, this will lead to increased traffic that has to be served by the deployed networks. Moreover, the energy consumption and the configuration/management complexity will be significantly increased, too. Current network infrastructures and their associated management systems face problems in keeping up with such stringent requirements. Therefore, it is essential to reconsider the design and the management of the Future Networks. An important goal in this direction is to achieve the best ratio of performance to energy consumption and at the same time assure manageability. This paper presents a general theoretical problem formulation for Energy-Aware Traffic Engineering and a distributed Traffic Engineering scheme (ETE), inspired by the previous formulation, that provides load balancing and energy-awareness in accordance with the operator's needs. Results from trace-driven simulations confirm the capability of ETE to meeting the needs of Future Networks.**

Keywords-network management; traffic engineering; energy-awareness; load balancing;

I. INTRODUCTION

Recently, *Network Operators* raised their interest in providing *energy-aware* network operation, putting this objective in high priority in their goals list. 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.

Moreover, in the direction of supporting complex heterogeneous network infrastructures and several services for a rapidly growing customer population, the network operators have to use a large number of network devices, placed in complex and difficult to manage network deployments. *Traffic Engineering* plays a crucial role in determining the performance and reliability of these 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.

Taking into account the aforementioned major objectives, we provide a general problem formulation for *load balancing* and *energy-awareness* in the network. A common practice of the network operators is to upgrade their infrastructure when the *maximum link utilization* exceeds a particular threshold (close to 40%-50%). We follow a traffic engineering problem formulation where the main objective is to *minimize the maximum utilization* in the network. By maintaining low link utilization, our approach allows the network operators to optimally exploit the capabilities of the existing infrastructure for a longer time. This policy reduces significantly the *Capital Expenditures (CAPEX)*. Furthermore, we *minimize the energy consumption* by turning the *idle* and the highly *energy-consuming* links (lines of the networks cards), into *sleeping mode.* In other words, based on the network conditions and the traffic requests we try to find the optimal set of links that could be turned into sleeping mode. In this way we achieve optimal *Operational Expenditures (OPEX)*. The previous problem formulations lead to optimal load balancing and energy-consumption levels in the network. Therefore, we could use them as a performance benchmark. In order to smoothly introduce the aforementioned major issues in real network deployments, we propose a *distributed Energy-Aware Traffic Engineering (ETE)* scheme. ETE is "governed" by a *low-complexity heuristic algorithm* that is executed in an autonomous manner, using monitoring of the status of the network and making automatic decisions.

The rest of the paper is organized as follows. Section II presents the state of the art, and briefly discusses the main contribution of the paper. In section III we describe the problem formulation and the ETE scheme. Section IV presents the evaluation study of ETE. Finally, in section V we summarize and we pave the way for future research actions.

II. RELATED WORK

A. *Traffic engineering*

Traffic engineering receives huge attention as one of the most important mechanism seeking to optimize network performance and traffic delivery. The authors in [1] give an overview of the traffic engineering approaches that emerged the last years and placed focus on two major issues: quality of service (QoS) and network resilience. They provide a general classification of these traditional-objective traffic engineering approaches: Intradomain vs. Interdomain [2], MPLS-based vs. IP-based [3, 4], Offline vs. Online [4, 5], Unicast vs. Multicast [7, 8]. The work in this paper is inspired by these traditional traffic engineering approaches.

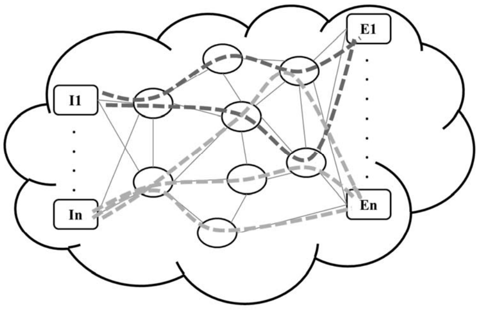

Figure 1. Example network topology.

B. *Energy consumption*

A challenging task is to identify the main parts of the Internet that dominate its power consumption and investigate methods for improving energy consumption [9]. Moreover, the authors in [10] 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. Recently, routing, rate adaptation and network control are mobilized towards energy-efficient network operation [11 - 13]. Unfortunately, none of these approaches provide a general problem formulation in the direction of "coupling" the traditional traffic engineering objectives with the modern objectives (like energy-awareness). This paper is an attempt to "modernize" the research in this field.

III. ENERGY-AWARE TRAFFIC ENGINEERING

In this section we give a general formulation of the load balancing and the energy efficiency problems for the operator's networks. Then, we present a distributed *Energy-Aware Traffic Engineering* scheme that follows the guidelines provided by the theoretical study. We consider a network model, as depicted in Figure 1, where each ingress router may have traffic demands for a particular egress router or set of routers. We use multiple paths (MPLS tunnels) to deliver traffic from the ingress to the egress routers. We must mention here that 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 [14]). In addition, 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. Table I contains the definition of the variables used in our problem formulation.

A. *Load balancing problem formulation*

We assume that for each IE (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. A fraction of the traffic x_{ip} is routed across path p ($p \in P_i$). We formulate the problem of optimal splitting the traffic of each IE pair across the available paths, assuring that the maximum link utilization (total traffic on an active link divided by the link capacity) in the network is minimized (in this way balanced and stable network operation is assured [15]):

TABLE I. 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
a_l	Binary variable: 0 if link l is sleeping, 1 if link l is active
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
E	Demand of the operator in energy consumption

$$\min_{x_{ip}} \max_{l \in L} \sum_{i \in IE} \sum_{p \in P_i} a_l \frac{x_{ip} T_i}{c_l},$$

$subject \quad to:$

$$x_{ip} \geq 0, \forall p \in P_i, \forall i \in IE$$

$$c_l \geq \sum_{i \in IE} \sum_{p \in P_l} x_{ip} T_i, \forall l \in L$$

$$\sum_{p \in P_i} x_{ip} = 1, \forall i \in IE$$

$$r_{ip} = x_{ip} T_i, \forall p \in P_i, \forall i \in IE$$

$$\sum_{p \in P_i} r_{ip} = T_i, \forall i \in IE$$

$$a_l = \{0,1\}, \forall l \in L$$

$$x_{ip} = [0,1], \forall p \in P_i, \forall i \in IE$$

The previous constraints ensure that: the fraction of traffic for a specific IE 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.

B. *Energy consumption problem formulation*

Then, we try to introduce energy-awareness in the previous load balancing procedure by identifying the set of links in the network that could be turned into sleeping mode. Therefore, we formulate the problem of finding the optimal set of "sleeping" links in order to achieve minimum energy consumption in the communication (sum of the energy consumption of the active links):

$$\min_{a_l} \sum_{l \in L} e_l a_l ,$$

$$subject \quad to:$$

$$x_{ip} \geq 0, \forall p \in P_i, \forall i \in IE$$
$$a_l - u_l \geq 0, \forall l \in L$$
$$u_l = \sum_{i \in IE} \sum_{p \in P_i} \frac{a_l}{c_l} x_{ip} T_i, \forall l \in L$$
$$r_{ip} = x_{ip} T_i, \forall p \in P_i, \forall i \in IE$$
$$\sum_{p \in P_i} r_{ip} = T_i, \forall i \in IE$$
$$\sum_{p \in P_i} x_{ip} = 1, \forall i \in IE$$
$$a_l = \{0,1\}, \forall l \in L$$
$$x_{ip} = [0,1], \forall p \in P_i, \forall i \in IE$$

The constraints are similar to the previous formulation. We also need to ensure that the utilized links cannot be turned into sleeping mode.

C. *Operator governed heuristic mechanism*

In this section we present a *distributed heuristic mechanism* which approaches the optimal *energy-aware traffic engineering solution*. The main "cornerstones" in the proposed mechanism are the following *low-complexity* and *distributed* algorithms:

- **LB**: *Given the a_l values for the links in the network, find the corresponding x_{ip} values that provide balanced network operation in terms of link utilization.* In order to provide an efficient solution we investigate for each IE node pair the paths that goes through the maximum utilized link. Then, we "relieve" this link by moving a portion of traffic Δx and provisioning it proportionally to the rest paths (progressive filling [15]). This procedure continues till convergence to the optimal x_{ip} values.
- **ES**: *Given the x_{ip} values resulted from* **LB**, *find the maximum set of links that could be turned into sleeping mode.* For each IE node pair we find the routers that are part of the active routes and turn the lines of their network card that are not used (by any path in the network) into sleeping mode.

The proposed mechanism (Figure 2) gets as input the operator request, as far as the energy consumption is concerned (E). Then, **LB** and **ES** are applied, by each IE node pair i in order to balance the link utilization in their paths and put the links that are not utilized into sleeping mode. Next, the new energy consumption level is compared to E in order to realize if we have reached the desired state. If not, the heuristic mechanism continues by excluding the path p with the minimum $x_{ip}T_i$ (lightest path). The heuristic mechanism iterates based on the updated P_i values, optimizes x_{ip} and a_l values $\forall p \in P_i, l \in L_i$ and finally, stops when the operator's energy consumption goal is achieved.

D. *Implementation-Deployment issues*

In order to give a thorough presentation of the proposed mechanism we discuss several deployment issues that arise when trying to apply the ETE scheme in real network deployments. Firstly, ETE 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, ETE is implemented on top of the router functionality (software package) handling the basic functionalities that are offered (sleeping mode, etc.).

IV. EVALUATION

In this section we present the evaluation study of the proposed scheme. In order to provide realistic simulation results, we use real ISP topologies and traces provided by Rocketfuel tool [16]. In our simulation scenario we consider Tiscali (3257) traces and a network topology consisted of 18 routers and 77 links. We compare the performance of ETE to OSPF-TE [17] that was applied in Tiscali network when the traces were collected.

Figure 3 depicts the utilization of the links in the network when ETE and OSPF-TE are applied. We observe that ETE is able to keep the link utilization at low levels using the minmax link utilization policy that is adopted. On the other hand, OSPF-TE uses a dynamic procedure to calculate the link weights in order to route the traffic efficiently which could lead to link overutilization.

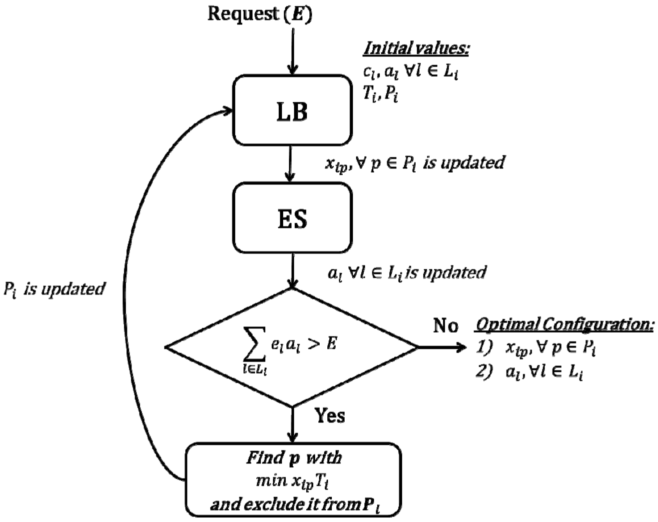

Figure 2. Heuristic energy-aware load balancing mechanism.

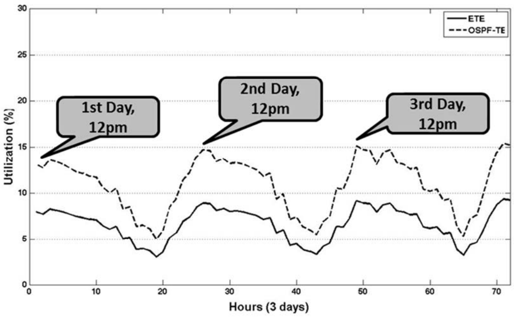

Figure 3. Link utilization when ETE and OSPF-TE are applied.

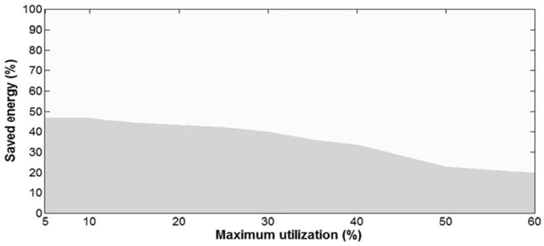

Figure 4. Percentage of saved energy vs. maximum link utilization.

Then, we plot the percentage of the initially consumed energy that is saved when ETE is applied. Similar to the previous scenario, we consider Tiscali traces in order to build a relationship between the load of the traffic that must be supported in the network and the energy saving that could be achieved by ETE. Figure 4 visualizes that when the maximum link utilization is low, the energy saving is close to 50%. The percentage of saved energy continually drops while the traffic in the network grows and therefore the utilization of the links is getting high.

Lastly, Table II presents the existing tradeoff between the energy consumption and the maximum link utilization in the network. The first column contains the operator's request, as far as energy saving is concerned. In addition, in the next two columns we observe the percentage of the links that must be turned into sleeping mode and the routes that will be excluded in order to approach the corresponding E values. The last column presents the balanced link utilization that is achieved by ETE for each desired E level. It is obvious that there is an important tradeoff between the balanced and energy-aware network operation which is handled by ETE, based on the operator's goals.

V. CONCLUSIONS

In this paper we presented a traffic engineering theoretical problem formulation which inspired the design of an *Energy-Aware Traffic Engineering* (ETE) scheme that try to meet the requirements of the future networks and pave the way for new "modern" traffic engineering approaches. The trace-driven simulation results indicate that ETE is capable to achieve load balancing and energy-awareness. Future plans include: extended theoretical study of the proposed scheme, enhancement with learning and autonomic features and implementation using commodity hardware.

TABLE II. ETE PERFORMANCE - TRADEOFF

Requested percentage for energy saving *(E)*	**Percentage of "sleeping" links**	**Percentage of routes excluded**	**Maximum link utilization**
10%	5%	2%	6%
20%	18%	8%	13%
30%	24%	13%	21%
40%	36%	18%	42%
50%	45%	22%	58%

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