O-Gene: towards an open green network control plane

Pasquale Donadio
Alcatel-Lucent Italia
Milan, Italy
pasquale.donadio@alcatel-lucent.com

Silvia Russo, Roberto Canonico, Giorgio Ventre
Dipartimento di Ingegneria Elettrica e Tecnologie dell'Informazione
Universita' degli Studi di Napoli Federico II, Napoli, Italy
name.surname@unina.it

***Abstract*—Recent contributions on energy-aware management, aimed at improving the energy efficiency of network infrastructures are based on a combined use of two levers: power consumption optimization obtained by (wholly or partially) switching off a single network device and traffic engineering strategies (with related algorithms) that, given the traffic model on a daily time period, minimize the global energy consumption avoiding traffic congestion. Switches, routers and links of the actual Internet are often represented by simple power consumption models, based on just a few states (typically, on and off). Time for off-to-on switching is often ignored. We claim that complex large-scale network infrastructures need an energy-conscious control plane, which is able of quickly configuring the network by taking into account both energy efficiency goals and QoS constraints. In this paper we present a green extension to the GMPLS network control plane, that is able of minimizing the global power consumption under QoS constraints. Time for fully activating components that were initially in stand-by or off is considered as a QoS requirement.**

***Keywords*-Green routing; Network Management; GMPLS control plane; Path Computation Element; OSPF-TE**

I. Introduction

Over the years, the Internet has become a central tool for society. Its large adoption and strength originates from its architectural, technological and operational foundation: a layered architecture and an agreed-upon set of protocols for the sharing and transmission of data over practically any medium. However, the growth of such a global-scale infrastructure, has recently raised new concerns. It has been recently estimated that Information and Communication Technology (ICT) sector accounts for 4% of the worldwide primary energy consumption. The expansion of the Internet incurs increased energy consumption, thus attracting a lot of attention on energy efficient networking [1], in particular in the context of optical networks [2]. Since the seminal work by Gupta and Singh [3] the research community has started developing technologies for manufacturing energy efficient network devices, methodologies for power aware network design, as well as energy management strategies for reducing energy wastes of networks in operation. The field of green networking has been attracting a growing attention during the last years [4], [5], but, only a limited number of recent works have been devoted to energy-aware traffic engineering and network design. Different preliminary studies evaluate the potentials and the actual applicability of energy-aware routing procedures [6], [7], [8], [9]. As an example, the approach proposed in [10] aims at switching off the linecards (network links) guaranteeing QoS constraints (maximum utilization and maximum path length constraints) in a scenario where an hybrid *Multi Protocol Label Switching/Open Shortest Path First* (MPLS/OSPF) scheme is adopted. Additional recent contributions on energy-aware network management are mainly focused on methods for switching off links solely based on network topology features (i.e. traffic demands are ignored) [11], [12], distributed algorithms to determine the operating configuration of each node (energy consumption minimization) [13], and new energy-aware protocols [14], [15]. Energy efficiency has also attracted much interest in the context of routing strategies for *Mobile Ad-hoc Networks* (MANETs) [16], where the main concern is mainly reducing the speed of battery discharge in mobile terminals. In this paper we propose a novel approach for designing a green network control plane for *All Optical Networks* (AONs), based on the concept that the energy demand of today's network devices arises from increasing user traffic and router capacities, which are not compensated by a corresponding increase in silicon energy efficiency. In fact, most network hardware is designed to operate constantly at maximum capacity, irrespective of the traffic load, even though their average utilization lies far below the maximum. These observations have motivated adapting the network capabilities, and thus its energy requirements, to the actual traffic profiles. This goal may be pursued by combining two different approaches: (i) the implementation of power management primitives in the hardware platforms of networking devices, similar to those already implemented in general-purpose computing systems, and (ii) the definition of a green control plane whose goal is to find a network configuration that leads to minimal global power consumption.

The main contribution of this paper is the design of control plane extensions providing a uniform way for the network resource orchestration to access the green networking capabilities of devices. This novel architecture and the related extensions is called O-Gene - *Open GrEen network control plaNE*. The remainder of this paper is organized as follows. The second section briefly refers to the context of All Optical Networks. The third section describes how we propose to extend a *Path Computation Element* (PCE)-based architecture with green management features. The fourth section presents an energy efficient extension of the existing OSPF-TE routing protocol and the power consumption model used to compare alternative routing paths. In the fifth section we evaluate by simulation the energy efficiency of our solution in a small scale network by using a power consumption model of a real optical network switch. Finally the sixth section concludes the paper.

II. Context

The Internet infrastructure is essentially an interconnection of several heterogeneous networks called Autonomous Systems that are interconnected with network equipments called gateways or routers. In the core-network segment, routers are interconnected through links which are mostly based on optical transmission technologies. The adoption of optical technologies is recently emerging also in access segments. In this paper we present a possible solution for reducing energy consumption by means of an energy-conscious network control plane. Our proposal is targeted to *Automatically Switched Optical Network/Generalized MPLS* (ASON/GMPLS) networks. We extend the routing (i.e OSPF-TE, *Open Shortest Path First-Traffic Engineering*) and signalling (i.e RSVP-TE, *Resource Reservation Protocol*) protocols to choose the most power-efficient configuration for the transport layer. By enabling resilient, automated and power-efficient networks, GMPLS brings a number of CAPEX and OPEX advantages in addition to eco-benefits.
The first step towards a high bit-rate core network was the creation of electro-optical networks. In these kinds of networks, although the signal travelling through them was optical, all the processing in both ends of the connection and in the intermediate nodes was done in the electric domain. That is why they are also named opaque networks, that is, because the signal does not remain all the way from an end to the other in the optical domain; an *optical-electrical-optical* (OEO) conversion must be done at some points to ensure a correct routing and *Quality of Service* (QoS).
However, despite the improvements introduced by opaque networks, the limitations of the electrical processing of the signal was an important bottleneck for achieving a low-power/high bit-rate core network, so that the next step was migrating the backbone towards *All Optical Networks* (AONs), where the routing and the processing was done in the optical domain. *Automatically Switched Transport Network/Automatically Switched Transport Network* (ASON/ASTN) is mainly the architecture used by these kinds of networks in conjunction with GMPLS as the technology used by the control plane.

The GMPLS framework is considered to be the emerging control plane solution for future optical networks. The main functionality that the GMPLS control plane offers in optical networks is the dynamic establishment and teardown of end-to-end optical connectivity. GMPLS currently does

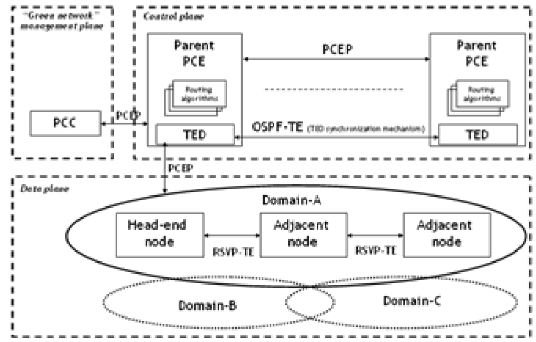


Figure 1: GMPLS/PCE architecture integration

not include any mechanism to take into account energy consumption parameters when identifying end-to-end paths or disseminating the status of network elements with respect to their power consumption.
What is missing is the connection between the network control plane and the *Optical Transport Network* (OTN) equipment that takes in account network management layer requirements and translates it in optical network resources with the objective to minimize the overall energy consumption while providing the QoS requested by the application.

III. A PCE-based Architecture for Green Optical Networks

Optical networks are complex infrastructures whose architecture is defined as a combination of layers and planes. *Dense Wavelength Division Multiplexing* (DWDM) is the emerging solution at the transport layer. The ITU-T G.872 standard defines the general architecture at the transport layer. Provisioning of lightpaths in traditional optical networks was a lengthy process. To overcome this limitation, ITU-T has recently proposed the ASON architecture, which utilizes a control plane to provide fast and reliable lightpaths within the optical transport network. In this context, the GMPLS model defined by the *Internet Engineering Task Force* (IETF) appears as the most promising technology to implement the functionalities of the ASON control plane. In this section, we propose an innovative architecture where GMPLS is extended so that management procedure can pursue both energy reduction objectives and satisfaction of users' QoS requirements. To enhance the GMPLS control plane with *green capabilities* we introduce new metrics and path selection algorithms in the PCE [17]. A PCE is a functional element that cooperates with similar entities and with network devices to compute the best possible path through multiple domains. The PCE function may implemented either as a centralized service or as a distributed architecture involving one agent in each device. Our proposal assumes that network devices are able to provide PCEs with energy consumption information. A PCE receives path computation requests from entities known as *Path Computation Clients*

(PCCs) (Figure 1). A PCE holds limited routing information from other domains, allowing it to possibly compute better and shorter inter-domain paths than those obtained using the traditional per-domain approach. Among other purposes, PCEs are also being advocated for CPU-intensive computations, minimal-cost-based TE-LSP placement, backup path computations, and bandwidth protection. Along with the process of identifying the requirements and development of the architecture accordingly, a plethora of work is underway at the PCE IETF WG aimed at defining new PCE communication protocols and introducing extensions to existing underlying routing protocols.

IV. Protocol design for energy efficient routing

Implementing an energy efficient routing within GMPLS requires spreading of additional knowledge throughout the control plane. Such knowledge regards current power consumption for each of the network nodes and links. Since GMPLS uses an IGP protocol to exchange label information within the network, this family of protocols is a perfect candidate to be extended. Our proposal extends the OSPF protocol. In particular, we consider opaque *Link State Advertisements* (LSA) of the OSPF protocol for spreading current power consumption values. New *Type, Length, Value* (TLVs) to the TE extensions for OSPF have been added. The format of a standard TE LSA packet, as defined in [18], is shown in figure 2. TLVs can be included in a LSA payload. TE LSA defined two types of top-level TLVs. We propose to add sub-TLVs to link-level TLV. Thus, the energy information is carried by setting up new sub-TLVs inside Link TLV (type 2) of TE LSAs. Type in sub-TLVs is considered in the range of 32768-32777, which is reserved for experimental uses. Value is defined to carry the energy information. It is composed of the following information:

- The energy information, normally a value assigned to represents the power consumption (mW);
- The link status, composed by 12 power status values as defined in EMAN [19]. An EMAN Power State Set represents an attempt for a standard approach to model the different levels of power of a device;
- The transition time matrix (12x12) consisting of the time required to transit from a link status to another one.

The flooding procedure follows the standard procedure of OSPFv2 flooding. After receiving a new LSA, the node decides whether to forward the LSA or discard it according to the carried timestamp. Link State Database is updated upon receiving valid LSAs. A node that does not support the newly defined TLVs ignores them but forwards them to its neighbours. In a PCE-based architecture, a routing decision is taken when a request for a new lightpath is submitted to the network. A commonly used criterion is to choose minimum-hop-count paths. Our goal is to base the routing decision on a minimal energy consumption increase, by also

```
 0                   1                   2                   3
 0 1 2 3 4 5 6 7 8 9 0 1 2 3 4 5 6 7 8 9 0 1 2 3 4 5 6 7 8 9 0 1
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|            LS age             |    Options    |      10       |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|       1       |                   Instance                    |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|                     Advertising Router                        |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|                     LS sequence number                        |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|         LS checksum           |             Length            |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|             Type              |             Length            |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|                            Value...                           |
.                                                               .
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
```

Figure 2: OSPF-TE LSA format

taking into account both minimum bandwidth and maximum activation time as QoS constraints. To do so, we assume that routing decision are taken by execuiting the classical Dijkstra algorithm on the network graph, where a link's cost is expressed as follows:

$$c_{ij} = c_{ij}^{E} + c_{ij}^{UB} + c_{ij}^{T} = \\ = \begin{cases} E_{ij} & \text{if } \{UB_{ij} \geq B_{min}\} \text{ and } \left\{T_{ij}^{ON} \leq T_{MAX}^{ON}\right\}, \\ \infty & \text{else} \end{cases} \tag{1}$$

where c_{ij} is the cost per edge, c_{ij}^{E}, c_{ij}^{UB} and c_{ij}^{T} are respectively the *Energy cost*, the *Unreserved Bandwidth cost* and the *ON time cost* on link (i,j). In particular:

$$c_{ij}^{E} = E_{ij}$$

$$c_{ij}^{UB} = \begin{cases} 0 & \text{if } UB_{ij} \geq B_{min}, \\ \infty & \text{else} \end{cases}$$

$$c_{ij}^{T} = \begin{cases} 0 & \text{if } T_{ij}^{ON} \leq T_{MAX}^{ON}, \\ \infty & \text{else} \end{cases}$$

where:

- $E_{i,j}$: possible increase of power consumption of the link (i,j);
- $UB_{i,j}$: unreserved available bandwidth value on link;
- B_{min}: minimum guaranteed bandwidth on the link;
- $T_{i,j}^{ON}$: time for transitioning from the current status to ON for the port connected to link;
- T_{MAX}^{ON}: maximum activation time for the whole path.

Green extension needs a support from the underlying hardware. We make the following assumptions based on today's typical router architectures and hardware in designing green extension. However, most of them can be relaxed to take advantage of better hardware support in the future without impacting the basic Green problem formulation and solution. First, a line-card can have multiple ports, and each port may connect to a link. Consider that the possible states of a network interfaces are only on and off. When a link is put to off-mode, the port that connects to the link can be turned off. Second, a link can be put to off-mode only when there is no traffic in both inbound and outbound directions, which is based on the fact that the transceivers of inbound and outbound traffic do not have separate power control in most hardware. The Green model can be easily adjusted to allow turning on/off unidirectional links and, if the hardware supports it, will bring even more power saving than what we show in this paper. Third, a port or a line-card can wake up more or less quickly, controlled by its host router.

Actually the power consumption of a network interface i can be modeled as the follow:

$$PW_i = \left[on \cdot (StaticPW + DynPW \cdot \frac{curRate}{maxRate}) \right]_i \quad (2)$$

In addition, considering that the power consumption of a linecard n, with I_n set of interfaces, is equal to:

$$PW_n = \sum_{i \in I_n} PW_i + \left[StaticPW + DynPW \cdot \frac{curRate}{maxRate} \right]_n , \quad (3)$$

where:

- on: boolean variable representing the state of the interface. It is equal to 1 if the interface is in on-mode, 0 if off-mode;
- $StaticPW$: static power constant;
- $DynPW$: dynamic power constant;
- $maxRate$: maximum transmission rate;
- $curRate$: current transmission rate;

Note that both $StaticPW$ and $DynPW$ are device specifics but dynamic one multiplies the percentage of the occupied bandwith, so that dynamic power consumption depends on current rate and increases with B_{min}. We can describe the increase of power consumption for the interface i of the linecard n, as the sum of the interface contribution and the linecard contribution of the interface:

$$E_i = \left[\overline{on} \cdot StaticPW + B_{min} \cdot \frac{DynPW}{maxRate} \right]_i + \left[B_{min} \cdot \frac{DynPW}{maxRate} \right]_n \quad (4)$$

Thus, the increase of power consumption of the link (i,j) is equal to:

$$E_{ij} = E_i + E_j \quad (5)$$

Green route calculation uses the information in the *Traffic Engineering Database* (TED), flooded by the TE LSAs, and locally specified constraints on the link attributes. The most stringent constraint is that a minimum Unreserved Bandwidth be available at all links along the path; all the links that do not meet the constraint are removed.

The cost of a path is the sum of costs of all its edges:

$$C_{sd} = \sum_{i,j \in P_e} c_{ij} \quad (6)$$

where P_e is the set of edges of path P.

V. Results and discussion

In this section we present a preliminary evaluation of the proposed Green routing algorithm, showing its effectiveness in terms of energy savings. We consider a simple network consisting of eight nodes connected by fifteen bidirectional links with either 1 Gbps or 10 Gbps capacity, as it is shown in Figure 4. In our node equipment model we have assumed as a reference a subset of the Alcatel-Lucent Multiservice Switch 1850-TSS320, shown in Table I. In detail, we have considered the equipment for each node shown in Table II. The energy model and the routing algorithm were implemented in MATLAB version R2012a. Routes were computed by considering a link cost computed according to formula 1. In this section, the results of our proposed model are discussed and evaluated, with focus on the energy cost reduction. To evaluate the effectiveness of our Green routing algorithm, we compared the routes determined by our algorithm to shortest paths (in terms of hop count).

In order to evaluate the effectiveness of our routing algorithm under various network conditions, we assume that 12 traffic flows are submitted to the network. Each flow requires a minimum guaranteed bandwidth randomly chosen between 0.2 Gbps and 1.4 Gbps. These flows enter the network in the nodes 1, 6, 7 and 8, and exit the network at nodes 1, 2, 5 and 6 (see Table III). The twelve flows have a duration of 60 minutes but start every five minutes, so leading to an increasing network load in the first hour and to a decreasing load in the second hour. By summing up the energy consumption of all the eight network devices we obtain the overall energy consumption. Under the same load conditions, we compare the overall energy consumption of our Green routing algorithm against a Shortest Path algorithm that only takes into account the bandwidth constraint, assuming that each port can wake up quickly ($T_{ij}^{ON} \leq T_{MAX}^{ON}$). Under this assumption, Figure 3 shows values used for link cost $c_{i,j}$ during simulation process for each link. Note that due to display cost curves, the infinity link cost value is represented by a large value (equal to 100). Figure 4a and Figure 4b show the different set of link used by Source-to-Destination paths that are chosen by Shortest Path and Green algorithms respectively during our experiment to accommodate the 12 traffic flows. Note that the high path redundancy and low link utilization provide unique opportunities for power-aware traffic engineering. When there are multiple paths between the same source-destination (SD) pair, and the traffic volume on some paths is low, one can move the traffic to a fewer number of paths so that the other paths do not carry any traffic for an extended period of time. Routers that have idle links can then put the links to off-mode for energy conservation. Figure 5a shows the overall power consumption during the experiment. By integrating power consumption over time, we conclude that our Green routing algorithm leads to a 14% energy reduction with respect to a network in which the Source-to-Destination path is computed as the shortest path compatible with the bandwidth constraints and to a 50% energy reduction with respect to the today's networks in which devices are powered on at full capacity 24×7 but highly under-utilized most of the time. The Green routing algorithm penalizes idle links to reuse busy ones. Due to this, the mean number of hops increase with respect to the SP algorithm. As shown in Figure 5b, the number of hops of each selected route is higher by using the proposed algorithm (green line) than that using the SP algorithm (red line). However the difference between two average values (dotted lines) is maintained below one hop. Additional tests putting down $(4, 5)$ link before the eighth traffic request, show that Green routing energy reduction decreases by 2% and the average hop count is one hop longer than the result using SP algorithm.

Table I: ALU-1850 TSS-320 Optical Switch

ID		**#**	**description**	**maxRate [Gbps]**	**StaticPW [W]**	**DynPW [W]**
1	Node		TSS160C	320,0	30,0	0,0
1,1	Line Card	1	2x10Gbps	20,0	30,0	20,0
1,1,1	Interface	1	SFP 1x10Gbps	10,0	20,0	10,0
1,1,2	Interface	2	SFP 1x10Gbps	10,0	20,0	10,0
1,2	Line Card	2	SFP 2x10Gbps	20,0	30,0	20,0
1,2,1	Interface	1	SFP 1x10Gbps	10,0	20,0	10,0
1,2,2	Interface	2	SFP 1x10Gbps	10,0	20,0	10,0
1,3	Line Card	1	SFP 10x1Gbps	10,0	30,0	20,0
1,3,1	Interface	1	SFP 1x1Gbps	1,0	5,0	5,0
1,3,2	Interface	2	SFP 1x10Gbps	1,0	5,0	5,0
1,3,3	Interface	3	SFP 1x1Gbps	1,0	5,0	5,0
1,3,4	Interface	4	SFP 1x10Gbps	1,0	5,0	5,0
1,3,5	Interface	5	SFP 1x1Gbps	1,0	5,0	5,0
1,3,6	Interface	6	SFP 1x10Gbps	1,0	5,0	5,0
1,3,7	Interface	7	SFP 1x1Gbps	1,0	5,0	5,0
1,3,8	Interface	8	SFP 1x10Gbps	1,0	5,0	5,0
1,3,9	Interface	9	SFP 1x1Gbps	1,0	5,0	5,0
1,3,10	Interface	10	SFP 1x10Gbps	1,0	5,0	5,0

Table II: Nodes equipment

Node	**Linecard**	**# interfaces**	**$\mathbf{maxRate_i}$ [Gbps]**
Node 1	1	1	10,0
	2	1	10,0
	3	1	1,0
Node 2	1	2	10,0
	2	1	10,0
	3	2	1,0
Node 3	1	2	10,0
	2	3	1,0
Node 4	1	2	10,0
	2	1	10,0
	3	2	1,0
Node 5	1	2	10,0
	2	1	10,0
	3	2	1,0
Node 6	1	1	10,0
	2	1	10,0
Node 7	1	2	1,0
	2	1	10,0
Node 8	1	2	10,0

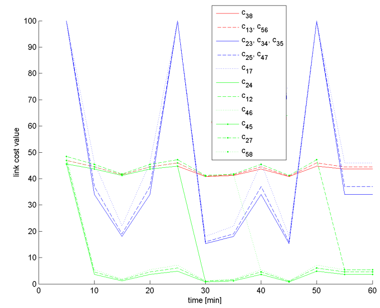
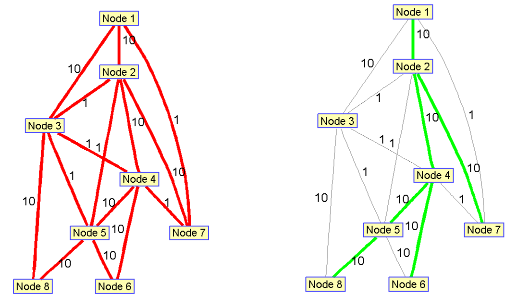


Figure 3: Green link cost during our experiment



(a) Minimum hops (b) Green

Figure 4: Different set of the used links

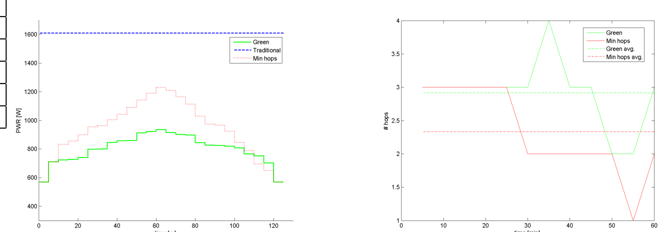

(a) Overall power consumption (b) Routing hops

Figure 5: Tradeoff between energy saving and hop count number

VI. Conclusion

The Network Control Plane of ASON/GMPLS networks may play a key role in the operational energy efficiency of network infrastructures. In this paper we propose a Path Computation Element (PCE) architecture which is able to compute end-to-end paths that meet users' QoS requirements and maximize the energy efficiency of the network. Our preliminary evaluation shows that the proposed energy efficient approach may lead up to 14% reduction in energy consumption for a moderate network load, compared to a traditional Shortest Path routing algorithm, while still

Table III: Flows specifics

Start	5’	10’	15’	20’	25’	30’	35’	40’	45’	50’	55’	60’
From $\rightarrow$ to	$1 \rightarrow 6$	$1 \rightarrow 6$	$6 \rightarrow 1$	$6 \rightarrow 1$	$1 \rightarrow 5$	$1 \rightarrow 5$	$8 \rightarrow 1$	$8 \rightarrow 2$	$8 \rightarrow 2$	$7 \rightarrow 1$	$7 \rightarrow 1$	$7 \rightarrow 5$
Amount data traffic [Gb]	5040	3240	1080	3240	4320	720	1080	3240	720	4329	3240	3240

maintaining acceptable routing hops numbers. Of course, this energy saving may decrease under heavy load conditions, when all the available resources need to be actively employed. We are currently implementing the Green OSPF-TE by extending an open source OSPF implementation.

Acknowledgment

This work was partially supported by the PRIN SFINGI project funded by the Italian Ministry of University and Research. It has been also supported by the ECONET project, funded by the European Commission under the 7th Framework Programme (FP7), Grant Agreement no. 258454.

References

[1] M. Pickavet, W. Vereecken, S. Demeyer, P. Audenaert, B. Vermeulen, C. Develder, D. Colle, B. Dhoedt, and P. Demeester, “Worldwide energy needs for ICT: The rise of power-aware networking,” in *Procs. of the 2nd IEEE International Symposium on Advanced Networks and Telecommunication Systems, (ANTS ’08)*, Dec. 2008, pp. 1 –3.

[2] J. Baliga, R. Ayre, K. Hinton, W. Sorin, and R. Tucker, “Energy Consumption in Optical IP Networks,” *Journal of Lightwave Technology*, vol. 27, no. 13, pp. 2391–2403, July 2009.

[3] M. Gupta and S. Singh, “Greening of the Internet,” in *Proceedings of ACM SIGCOMM 2003*. ACM, 2003, pp. 19–26.

[4] A. Bianzino, C. Chaudet, D. Rossi, and J.-L. Rougier, “A survey of green networking research,” *IEEE Communications Surveys & Tutorials*, vol. 14, no. 1, pp. 3 –20, 2012.

[5] R. Bolla, R. Bruschi, F. Davoli, and F. Cucchietti, “Energy efficiency in the Future Internet: A survey of existing approaches and trends in energy-aware fixed network infrastructures,” *IEEE Communications Surveys & Tutorials*, vol. 13, no. 2, pp. 223 –244, 2011.

[6] R. Bolla, F. Davoli, R. Bruschi, K. Christensen, F. Cucchietti, and S. Singh, “The potential impact of green technologies in next-generation wireline networks: Is there room for energy saving optimization?” *IEEE Communications Magazine*, vol. 49, no. 8, pp. 80 –86, August 2011.

[7] L. Chiaraviglio, D. Ciullo, M. Mellia, and M. Meo, “Modeling sleep modes gains with random graphs,” in *2011 IEEE Conference on Computer Communications Workshops (INFOCOM Workshops)*, April 2011, pp. 355 –360.

[8] A. Cianfrani, V. Eramo, M. Listanti, M. Polverini, and A. Vasilakos, “An OSPF-Integrated Routing Strategy for QoS-Aware Energy Saving in IP Backbone Networks,” *IEEE Transactions on Network and Service Management*, vol. 9, no. 3, pp. 254 –267, September 2012.

[9] S. Avallone and G. Ventre, “Energy efficient online routing of flows with additive constraints,” *Computer Networks*, vol. 56, no. 10, 2012.

[10] M. Zhang, C. Yi, B. Liu, and B. Zhang, “GreenTE: Power-aware traffic engineering,” in *Proceedings of the The 18th IEEE International Conference on Network Protocols*, ser. ICNP ’10. IEEE Computer Society, 2010, pp. 21–30.

[11] F. Cuomo, A. Abbagnale, and S. Papagna, “ESOL: Energy saving in the Internet based on Occurrence of Links in routing paths,” in *2011 IEEE International Symposium on a World of Wireless, Mobile and Multimedia Networks (WoWMoM)*, June 2011, pp. 1 –6.

[12] F. Cuomo, A. Abbagnale, A. Cianfrani, and M. Polverini, “Keeping the connectivity and saving the energy in the Internet,” in *2011 IEEE Conference on Computer Communications Workshops (INFOCOM Workshops)*, April 2011, pp. 319 – 324.

[13] A. Bianzino, L. Chiaraviglio, and M. Mellia, “GRiDA: A green distributed algorithm for backbone networks,” in *2011 IEEE Online Conference on Green Communications (GreenCom)*, Sept. 2011, pp. 113 –119.

[14] T. Mahmoodi, “Energy-aware routing in the Cognitive Packet Network,” *Performance Evaluation*, vol. 68, no. 4, pp. 338–346, April 2011.

[15] K.-H. Ho and C.-C. Cheung, “Green distributed routing protocol for sleep coordination in wired core networks,” in *6th International Conference on Networked Computing (INC 2010)*, May 2010, pp. 1 –6.

[16] N. Costagliola, P. G. López, F. Oliviero, and S. P. Romano, “Energy- and delay-efficient routing in mobile ad hoc networks,” *Mobile Networks and Applications (MONET)*, vol. 17, no. 2, pp. 281–297, Apr. 2012.

[17] A. Farrel, J.-P. Vasseur, and J. Ash, “A Path Computation Element (PCE)-Based Architecture,” RFC 4655 (Proposed Standard), Internet Engineering Task Force, August 2006. [Online]. Available: http://www.ietf.org/rfc/rfc4655.txt

[18] K. Ishiguro, V. Manral, A. Davey, and A. Lindem, “Traffic Engineering Extensions to OSPF Version 3,” RFC 5329 (Proposed Standard), Internet Engineering Task Force, September 2008. [Online]. Available: http://www.ietf.org/rfc/rfc5329.txt

[19] “Power State Management Profile DMTF DSP1027 – Version 2.0,” Distributed Management Task Force, December 2009. [Online]. Available: http://www.dmtf.org/sites/default/files/standards/documents/DSP1027_2.0.0.pdf