Proceedings Paper:

Al-Salka, MA and Elmirghani, JMH (2015) CORNETO: A Software System for Simulating and Optimizing Optical Networks. In: Proceedings of the 20th European Conference on Network and Optical Communications. The 20th European Conference on Network and Optical Communications, 30 June - 2 July 2015, London, UK. .

CORNETO: A Software System for Simulating and Optimizing Optical Networks

Mohammad Ammar Alsalka and Jaafar M. H. Elmirghani
School of Electronic and Electrical Engineering, University of Leeds, LS2 9JT, United Kingdom

Abstract— In this paper we present a software system that is being developed at the University of Leeds for simulating and optimizing energy efficient optical core networks. The system is called CORNETO, an acronym for CORe NETwork Optimization. The software implements many of the energy saving concepts, methods and computational heuristics that have been produced by the ongoing INTERNET, INTelligent Energy awaRe NETworks, project. The main objective of the software is to help network operators and planners green their networks while maintaining quality of service. In this paper we briefly describe the software and demonstrate its capabilities with two case studies.

Keywords— Energy Efficient Optical Networks; IP over WDM Networks, Energy-aware Optical Routing Heuristics, Network Simulation, Energy-efficient BitTorrent.

I. INTRODUCTION

The rapid expansion and proliferation of the Internet, broadband networks, and media-rich applications in recent years has considerably increased the energy consumption and the carbon footprint of the Internet. This has motivated vigorous research into methods of greening ICT networks in general, and backbone networks in particular. One of the first papers in this line of investigation is [1], in which the authors examined the energy savings that could be obtained by adopting aggressive sleep modes for various network devices. In [2], the authors introduced energy profiles aware routing as a network level energy reduction approach. In [3], the authors proposed energy-aware traffic engineering in which load is spread among multiple paths to obtain energy savings. In [4], the authors proposed applying traffic grooming methods and optical by-pass techniques to reduce the energy consumption of IP/WDM core networks. The authors of [5] proposed a network-wide power manager, called ElasticTree, which dynamically adjusts active network elements to save energy in data center networks. In [6] the authors designed and implemented a proxy-based BitTorrent architecture to reduce the energy footprint of P2P applications. In [7] the authors determined the optimal time seeders should stay online in order to minimize the globally consumed energy of a BitTorrent swarm. The authors of [8] approached the virtual network embedding problem with the objective of minimizing energy consumption.

The aim of the INTelligent Energy awaRE NETworks (INTERNET) project [9] is to reduce the carbon footprint of ICT networks by at least an order of magnitude. Toward this goal, our team has been investigating various ways of greening core optical networks, and a plethora of newly proposed concepts, methods and computational heuristics have been proposed. These methods spanned widely different aspects of the core network, including among other things, the efficient use of renewable energy [10], the optimal location of data centers [11], energy-optimized physical topologies [12], the optimal distribution of content and virtual machines across cloud networks [13], energy efficient BitTorrent protocols [14] [15], energy saving virtual network embedding schemes [16], and the use of caching to save energy when distributing media-rich content in IP/ WDM networks [17].

The software system described in this paper has been developed in order to integrate, homogenize, and expand these diverse energy saving measures. The system can be used by core network analysts, planners, and operators to understand the mutual interaction between the data and energy flow processes within a network. Interested readers can download the software from corneto.leeds.ac.uk.

II. BRIEF DESCRIPTION OF THE CORNETO SYSTEM

The CORNETO software system is comprised of three main modules, the Network Modelling and Analysis Module, the Network Simulation Module, and the Solvers Module, and uses an intuitive and powerful Graphical User Interface (GUI). Figure 1 shows a screen snapshot of CORNETO's GUI, with a model of the NSFNET network with its energy sources. Both renewable and non-renewable energy sources are used.

The software allows modelling of transmission losses in power lines, energy cost, and the carbon intensity of power plants. In this way, the software is not only capable of simulating the processes taking place within the data network, but it also takes into account the interaction between the data network and its energy sources.

CORNETO has built-in solvers for finding the optimum locations of green power plants and data centres, optimizing the replication of content and/or virtual machines across cloud networks, and for the optimized embedding of virtual network requests. Both exhaustive search and heuristic (near-optimum) solvers are developed and integrated in CORNETO.

To study the impact of BitTorrent traffic on the underlying core network, CORNETO is also equipped with a full BitTorrent simulator. Both traditional and energy-saving BitTorrent protocols are supported.

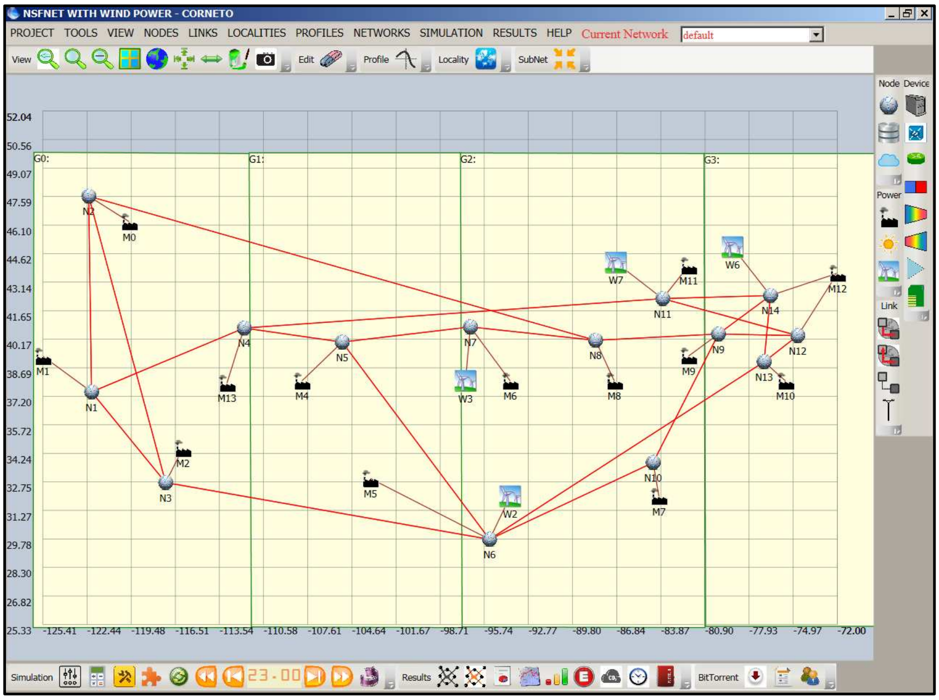

Figure 1: A screen snapshot of CORNETO's GUI, with a model of the NSFNET network.

The heart of the CORNETO software is a Routing Engine which is used to route traffic demands across the network. The system permits the user to experiment with various routing possibilities by choosing different routing heuristics, optimization targets, and link cost functions, Figure 2.

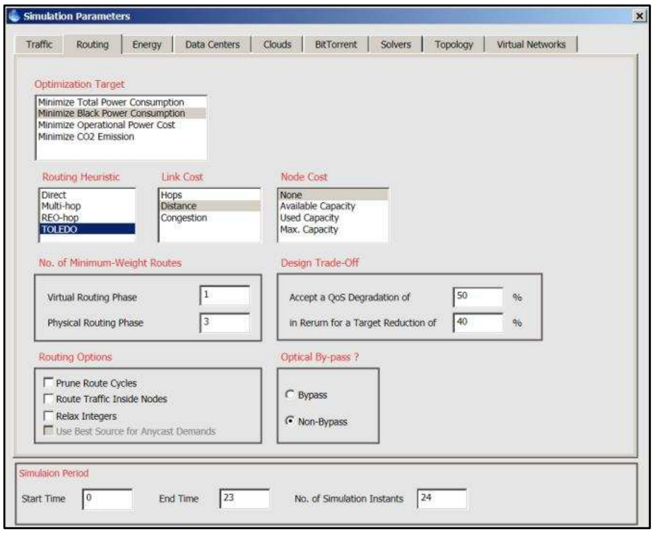

Figure 2: The Routing tab of the Simulation Parameters window in CORNETO.

In the following sections we present two case studies using CORNETO to demonstrate the savings in CO2 emission and non-renewable energy that can be obtained using energy-aware methods in IP/WDM networks. In both case studies, the default parameter values of network devices are as shown in Table 1.

Table 1: Default network device parameter values used in this paper.

Parameter	Value
Router port power consumption [18]	1000 W
Transponder power consumption [19]	73 W
Optical Cross Connect power consumption [20]	85 W
Multi/Demultiplexer power consumption [21]	16 W
EDFA power consumption [22]	8 W
Distance between EDFAs [4]	80 km
Number of wavelengths/fiber [4]	16
Capacity of a single wavelength [4]	40 Gb/s
Light speed in fiber	$2.083x10^8$ m/s

III. CASE STUDY 1: REDUCING ENERGY CONSUMPTION WITH ENERGY-AWARE ROUTING HEURISTICS

A number of energy-saving optical routing heuristics have been proposed for reducing the power consumption of core networks. In [4], the authors proposed the Multi-hop routing heuristic which uses traffic grooming methods and optical-bypass to reduce the power consumption of IP/WDM networks. In [10], the authors introduced the REO-hop routing heuristic as a means of minimizing the non-renewable power consumption of networks with access to green energy. Also, significant reductions in power consumption can be achieved if traffic demands are routed over minimum hop - rather than shortest distance - routes. This method has been used in the DEER-CD and DEER-VM heuristics [13], and the REOViNE virtual networks embedding scheme [16].

In CORNETO, we use a generic routing heuristic that extends the key concepts introduced by the heuristics mentioned above. It is called TOLEDO, an acronym of **T**arget **O**ptimization by **L**ight-path **E**xploration with **D**esign trade-**O**ffs.

Essentially, the heuristic works by exploring the n minimum-weight routes (where n is an integer ≥ 1) between the source and destination nodes of a demand pair, and estimating the target value (e.g. CO2 emission) when each of these routes is taken. The heuristic then uses the route that minimizes this target value. The heuristic also permits making balanced compromises between quality of service (route delay) and the value of the target to be minimized. This is achieved by allowing the network operator to determine two thresholds. The first is the minimum target reduction (TR_{min}) that must be obtained if a route other than the minimum-weight route is taken; and the second threshold is the maximum route-weight increase (W_{max}) that is tolerated if this alternative route is taken. The heuristic will only use an alternative route if the target reduction is greater than TR_{min} and, at the same time, the increase in route weight is less than W_{max}. In this way, the operator can control the trade-off between quality of service and the desired target.

In the following case study we investigate the effect of using various routing strategies on CO_2 emission of the NSFNET network shown in Figure 3. The network nodes are identical in terms of their architecture and equipment used. Nodes are fed with black (non-renewable) power from identical plants having a carbon intensity of 1.029 kg/kWh. The network extends across the four time zones of the US, and the average traffic demand in each time zone changes with time according to the profiles shown in Figure 4. Assuming optical non-bypass, a key question relates to the choice of routing method that would result in the minimum CO_2 emission, and further to how does the choice of routing method affect the quality of service (average traffic delay) of the network.

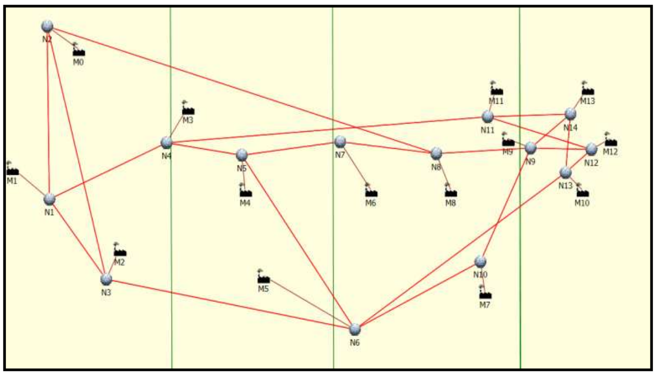

Figure 3: A model of the NSFENT with black power plants only.

To answer these questions, we used CORNETO to simulate the operation of the network under the five different operating scenarios shown in Table 2.

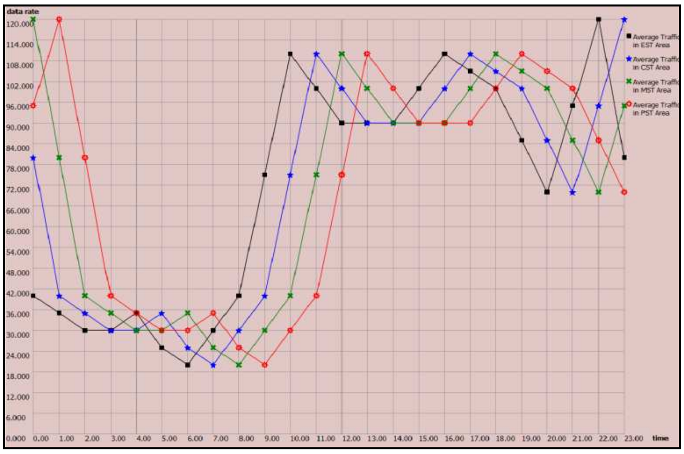

Figure 4: Variations of average traffic demand with time for the four time zones of the US.

Table 2: Five different operating scenarios (routing options) for the network shown in Figure 3. N_{vir} and N_{phy} are the number of minimum-weight routes to be explored in the virtual and physical routing phases respectively.

Scenario	**Routing Heuristic**	**Link Cost**	**Opt. Target**	N_{vir}	N_{phy}	TR_{min}	W_{max}
1	Direct	Distance	-	0	1	-	-
2	Multi-hop	Distance	-	1	1	-	-
3	TOLEDO	Distance	CO_2	1	3	10%	75%
4	TOLEDO	Hops	CO_2	1	1	-	-
5	TOLEDO	Hops	CO_2	1	3	10%	75%

The CO_2 emission curves generated by CORNETO are shown in Figure 5. Maximum CO_2 emission is produced when direct routing (Scenario 1) is used. CO_2 emission in Scenario 2 was reduced by up to 14%. This reduction is due to traffic grooming by the multi-hop heuristic. In Scenario 3, CO_2 emission was reduced by up to 19% compared to Scenario 1. This reduction is due to two factors: traffic grooming and TOLEDO's ability to find better routes with less CO_2 emission. Since the network nodes are homogeneous and have no sources of green energy, these 'better' routes are simply ones with fewer number of hops. In Scenario 4, which is a 'pure' minimum hop routing strategy, CO_2 emission was reduced by up to 22%. Scenario 5 had identical results to Scenario 4 because the network nodes are homogeneous. Hence, alternative routes with a hop count larger than the minimum-hop route cannot lead to reduced CO_2 emission.

Figure 5: CO_2 emission (kg/h) of the network in Figure 3 as a function of time (h), under the five scenarios shown in Table 2. For clarity, the curve for Scenario 5 is not shown as it entirely overlaps that of Scenario 4.

Figure 6 shows the average propagation delay curves for the five different Scenarios. It can be seen that direct routing has the minimum average delay. Using multi-hop routing (Scenario 2) increased the average delay by up to 42%. Scenario 3 increased delay by up to 47%. Finally, Scenarios 4 and 5 are identical and increased delay by up to 71%.

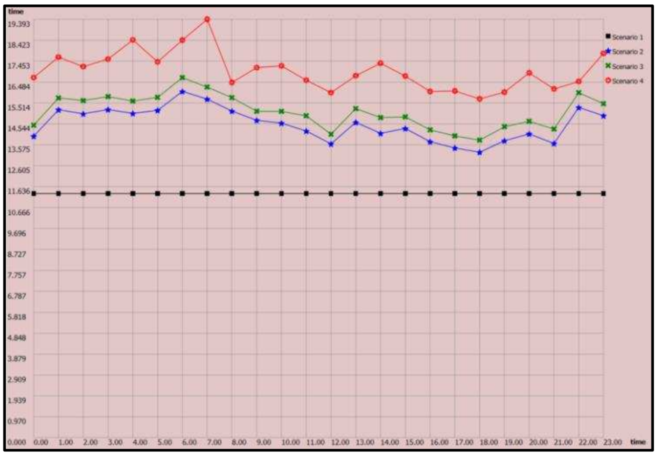

Figure 6: Average propagation delay (in milliseconds) for the network in Figure 3, under the five scenarios of Table 2. For clarity, the curve for Scenario 5 is not shown as it entirely overlaps that of Scenario 4.

From above, it is clear that if a network has homogenous nodes and identical power sources, simple minimum-hop routing will result in the minimum power consumption and CO_2 emission. However, if the network nodes are not homogenous, and/or if they are fed with energy from power sources of different characteristics, then minimum-hop routing will not necessarily result in the lowest energy consumption.

IV. CASE STUDY 2 : ENEGRY SAVING BITTORRENT

In order to allow network operators to evaluate the advantages of using the newly proposed locality-aware BitTorrent protocols on the power consumption of core networks, a comprehensive BitTorrent simulator was built into the CORNETO software. The simulator implements all the specifications of the original BitTorrent protocol [23], [24] and [25], and accounts for the newly proposed concepts of locality-aware BitTorrent [14], [26]. Here, we have implemented two types of locality awareness: locality-aware trackers, and locality-aware peers.

In locality-aware trackers, the tracker in a BitTorrent swarm must have information about the locations of the individual peers in the core network. This information is then used when a new peer requests an initial set of peers to communicate with, or if an existing peer requests a replenishment set when the number of peers they are communicating with drops below a certain level.

In locality-aware peers, each peer must have information about the location of all peers they are communicating with. The peer uses this information in two ways:

- When a peer needs to request a new file piece, then if this piece is available at more than one other peer, the requesting peer uses peer-locality information to request the piece from the 'nearest' peer in terms of hop-count.
- When a peer performs an optimistic un-choke, it uses peer-locality information to give hop-wise closer peers a higher probability of being unchoked.

To investigate the energy savings obtained by locality-aware BitTorrent protocols, we used CORNETO to simulate 500,000 BitTorrent peers exchanging a 128MB file. The peers are uniformly spread across the nodes of the NSFNET network shown in Figure 3. We compared the total energy spent throughout the BitTorrent session for the five scenarios shown in Table 3.

Table 3: Five different BitTorrent scenarios.

Scenario	Locality-Aware Tracker?	Locality-Aware Peers?	Peers Leave When Finished Downloading?
1	No	No	No
2	Yes	No	No
3	No	Yes	No
4	Yes	Yes	No
5	Yes	Yes	Yes

Figure 7 shows the BitTorrent simulation parameters used in this case study. The file size is 128MB (0.125 GB), and the file is divided into equal pieces of 16MB (0.015625 GB) each. When a peer wants to upload a piece, the simulator chooses a random connection speed (upload rate) uniformly distributed between a minimum and a maximum rate (0.001 and 0.01 Gb/s in Figure 7). A peer can request new pieces as long as its total download rate is still below some maximum value. Here, the maximum download rate is 100Mb/s (0.1 Gb/s).

To model variations in peer behavior, the user can adjust the simulation parameters so that peers can either join the swarm at the same time (flash crowd), or randomly join within a certain period of time. In Figure 7, peers join the swarm at random times within 60 seconds of the start of the simulation period. Similarly, when peers finish downloading they can either remain in the BitTorrent session, or randomly leave within a specified period.

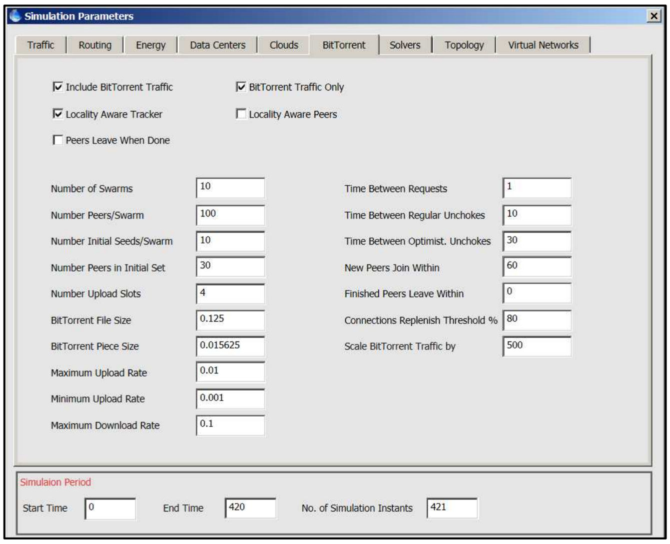

Figure 7: The BitTorrent evaluation parameters used in the case study.

If peers leave the swarm, the number of active connections for some peers may drop too much and the peer take more time to collect the pieces of the file. In order to minimize this effect, peers are allowed to replenish gone peers by requesting a fresh set of active peers from the tracker when the number of connections falls below some threshold. In Figure 7, an 80% minimum threshold is set.

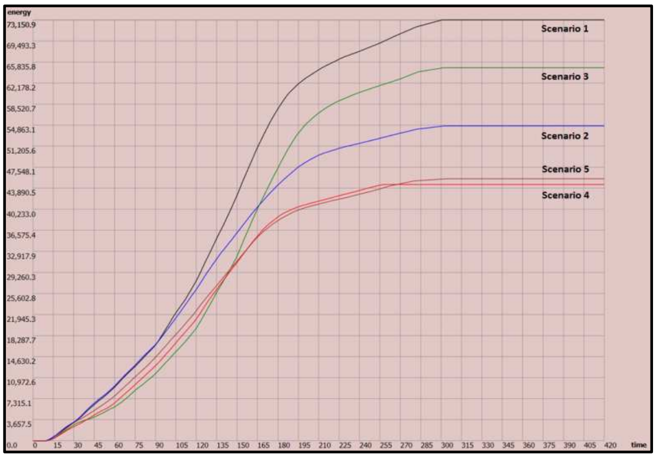

Figure 8: Total energy consumption (kW.s) of the NSFNET, for the five BitTorrent operating scenarios of Table 3.

The results for network's energy consumption are shown in Figure 8. Standard BitTorrent (Scenario 1) required the largest amount of energy to finish all downloads. Scenarios 2, 3, 4, and 5 were able to reduce energy consumption by 25%, 11%, 39%, and 37%, respectively. Minimum energy consumption is obtained when both locality-aware trackers and locality-aware peers are used. Allowing peers to leave as soon as they finish downloading (Scenario 5) has little influence on energy consumption in comparison to Scenario 4 (when peers do not leave). The most significant effect on reducing energy consumption is attained by using locality aware trackers.

V. CONCLUSIONS

In this paper we presented a software system for simulating optical core networks. The main aim of the software is to help network planners and operators reduce the energy consumption and carbon emissions of their networks. The system utilizes many of the concepts and methods that have been introduced by the INTERNET project. In this paper we presented some of these methods, and tested them within our software.

Our software incorporates a generic target-optimizing routing heuristic that allows network operators to experiment with various routing options and study the effect of these on the energy consumption and carbon footprint of their network. It has been shown in this paper that reductions in carbon emissions of up to 20% can be achieved by simply using an energy-efficient routing strategy, even in the absence of any green energy sources.

To account for BitTorrent traffic and reduce its effect on the energy consumption of core networks, our software incorporates an energy saving BitTorrent protocol that can be tested against traditional BitTorrent for performance and power consumption. Case studies presented in this paper have shown that energy savings of up to 35% can be obtained using a locality-aware BitTorrent protocol.

ACKNOWLEDGMENT

The authors would like to acknowledge funding from the Engineering and Physical Sciences Research Council (EPSRC), INTERNET (EP/H040536/1) and STAR (EP/K016873/1).

REFERENCES

[1] M. Gupta and S. Singh, "Greening of the internet," Proc. ACM SIGCOMM, Aug. 2003.

[2] J. Camilo, C. Restrepo, C. Gruber, and C. M. Machuca, "Energy Profile Aware Routing," in Proc. 1st Int. Workshop Green Commun. IEEE Int. Conf. Commun., Dresden, Germany, Jun. 2009, pp. 1–5.

[3] N. Vasic and D. Kostic, "Energy Aware Traffic Engineering," in Proc. 1st Int. Conf. Energy-Efficient Computing Networking (E-ENERGY), 2010, pp. 169–178.

[4] G. Shen and R. S. Tucker, "Energy-Minimized Design for IP Over WDM Networks" Opt. Commun. Networks, Vol. 1, No. 1, pp. 176–186, Jun. 2009.

[5] B. Heller, S. Seetharaman, P. Mahadevan, Y. Yiakoumis, P. Sharma, S. Banerjee, and N. McKeown, "ElasticTree: Saving Energy in Data Centre Networks," in USENIX NSDI, 2010.

[6] G. Anastasi, I. Giannetti, and A. Passarella, "A BitTorrent proxy for Green Internet File Sharing: Design and experimental evaluation," Computer Communications, vol. 33, no. 7, pp. 1–22, 2010.

[7] H. Hlavacs, R. Weidlich, and T. Treutner, "Energy efficient Peer-to-Peer File Sharing," The Journal of Supercomputing, vol. 62, no. 3, pp. 1167–1188, Apr. 2011.

[8] B. Wang; X. Chang; J. Liu, J.K. Muppala, Reducing Power Consumption in Embedding Virtual Infrastructures, IEEE Globecom Workshops (GC Wkshps), 2012, pp.714, 718, 3-7 Dec. 2012

[9] The INTelligent Energy awaRe NETworks (INTERNET) project, http://www.internet-project.org.uk/index.html.

[10] X. Dong, T. El-Gorashi, and J. M. H. Elmirghani, “IP over WDM Networks Employing Renewable Energy Sources,” Journal of Lightwave Technology, Vol. 29, No. 1, pp. 3–14, Jan. 2011.

[11] X. Dong, T. El-Gorashi, and J. M. H Elmirghani, “Green IP Over WDM Networks With Data Centres”, Journal of Lightwave Technology, Vol. 29 , No. 12 , pp. 1861–1880, Jun. 2011.

[12] X. Dong, T. El-Gorashi, and J. M. H. Elmirghani, “On the Energy Efficiency of Physical Topology Design for IP Over WDM Networks”, Journal of Lightwave Technology, Vol. 30, No. 12, JUN, 2012.

[13] A. Q. Lawey, T. El-Gorashi, and J. M. H. Elmirghani, “Distributed Energy Efficint Clouds Over Core Networks”, Journal of Lightwave Technology, Vol.32, No. 7, Apr. 2014.

[14] A. Q. Lawey, T. El-Gorashi and J. M. H. Elmirghani, “Energy-Efficient Peer Selection Mechanism for BitTorrent Content Distribution,” in Proc. of the IEEE Global Telecommunications Conference (GLOBECOM’12), pp. 1562-1567, Anaheim, California, USA, Dec. 2012.

[15] A. Q. Lawey, T. El-Gorashi, and J. M. H. Elmirghani, “BitTorrent Content Distribution in Optical Networks”, Journal of Lightwave Technology, Vol. 32, No. 21, Nov. 2014

[16] L. Nonde, T. El-Gorashi, and J. M. H. Elmirghani, “Energy Efficient Virtual Network Embedding for Cloud Networks”, Journal of Lightwave Technology, Vol. 33, No. 9, May 2015.

[17] N. Osman, T. El-Gorashi, and J. M. H. Elmirghani, “Caching in Green IP Over WDM Networks,” Journal of High Speed Networks, Vol. 19, No. 1, pp. 33-53, Jan 2013.

[18] Cisco Systems Inc., “Data sheet of CRS-1 8-slot chassis power systems.”

[19] Cisco Systems Inc., “Data sheet of Cisco ONS 15454 10-Gbps multi-rate transponder card.”

[20] Glimmerglass Cyber Solutions, “Data sheet of Glimmerglass Intelligent Optical System 500.”

[21] Cisco Systems Inc., “Data sheet of Cisco ONS 15454 100-GHz 4-CH Multi/ Demultiplexer.”

[22] Cisco Systems Inc., “Data sheet of Cisco ONS 15501 EDFA.”

[23] B. Cohen, “The BitTorrent Protocol Specification”, http://www.bittorrent.org/beps/bep_0003.html , Oct. 2013.

[24] Wiki.theory.org, “Bittorrent Protocol Specification v1.0”, https://wiki.theory.org/BitTorrentSpecification.

[25] J. Fonseca, B. Reza, and L. Fjeldsted, “BitTorrent Protocol version 1.0”, http://jonas.nitro.dk/bittorrent/bittorrent-rfc.html, Apr. 2005.

[26] R. Bindal, P Cao, W. Chan, J. Medved, G. Suwala, T. Bates, and A. Zhang, “Improving Traffic Locality in BitTorrent via Biased Neighbor Selection”, Proceedings of the 26th IEEE International Conference on Distributed Computing Systems (ICDCS’06), 2006.