GreenTouch GreenMeter Core Network Energy-Efficiency Improvement Measures and Optimization

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Abstract— This paper discusses energy-efficiency improvements in core networks obtained as a result of work carried out by the GreenTouch consortium over a five-year period. A number of techniques that yield substantial energy savings in core networks were introduced, including (i) the use of improved network components with lower power consumption, (ii) putting idle components into sleep mode, (iii) optically bypassing intermediate routers, (iv) the use of mixed line rates, (v) placing resources for protection into a low power state when idle, (vi) optimization of the network physical topology, and (vii) the optimization of distributed clouds for content distribution and network equipment virtualization. These techniques are recommended as the main energy-efficiency improvement measures for 2020 core networks. A mixed integer linear programming optimization model combining all the aforementioned techniques was built to minimize energy consumption in the core network. We consider group 1 nations' traffic and place this traffic on a US continental network represented by the AT&T network topology. The projections of the 2020 equipment power consumption are based on two scenarios: a business as usual (BAU) scenario and a GreenTouch (GT) (i.e., BAU + GT) scenario. The results show that the 2020BAUscenario improves the network energy efficiency by a factor of 4.23× compared with the 2010 network as a result of the reduction in the network equipment power consumption. Considering the 2020 BAU + GT network, the network equipment improvements alone reduce network power by a factor of 20× compared with the 2010 network. Including of all the BAU + GT energy-efficiency techniques yields a total energy efficiency improvement of 315× . We have also implemented an experimental demonstration that illustrates the feasibility of energy-efficient content distribution in IP/WDM networks.

Index Terms— *Cloud networks, Energy efficient networks, IP over WDM, MILP, Network virtualization, Virtual network embedding.*

I. INTRODUCTION

Internet traffic has been growing exponentially as a result of the continuously growing popularity of data intensive applications and the increasing number of devices connected to the Internet. It is estimated that by 2020 over 50 billion devices will be connected to the Internet. The Internet service model as we know it today is evolving to facilitate efficient communication and service provisioning. Cloud computing is at the center of this evolution. One of the main challenges facing cloud computing is adequately serving the increasing traffic demand while maintaining sustainability and enhancing profit margins through lower energy usage. Today the power consumption of networks is a significant contributor to the total power demand in many developed countries. For example, in the winter of 2007, British Telecom became the largest single power consumer in the United Kingdom, accounting for 0.7% of the total UK's power consumption . Driven by the economic, environmental, and societal impact, significant academic and industrial research efforts have recently been focused on reducing the power consumption of communication networks.

GreenTouch was a consortium of leading information and communications technology (ICT) research experts. It includes approximately 50 academic, industry, and nongovernmental organizations and plays an essential role in technology breakthroughs in communication network energy efficiency. The consortium was formed in 2010 to pursue the ambitious goal of bridging the gap between traffic growth and network energy efficiency. This is to be achieved by delivering architecture specifications and technologies needed to increase energy efficiency by a factor of 1000 compared with 2010 levels. Achieving this goal will help create a sustainable future for data networking and the Internet. The research areas investigated by GreenTouch included wired access networks, mobile networks, core networks and services, and policies and standards. Wireless networks are expected to achieve the highest savings followed by access networks and finally core networks.

The total power consumption is evaluated considering a 2010 network and a 2020 network. For the 2010 network, we consider the traffic in 2010 along with the most energy efficient commercially available equipment at that time. The 2020 network is based on projections of the traffic in 2020 and the reductions in the equipment power consumption by 2020. The projections of the 2020 equipment power consumption are based on two scenarios: a business as usual (BAU) scenario and BAU+GT scenario, where the technical advances achieved by the GreenTouch consortium will accelerate the reduction in equipment power consumption.

Network operators have traditionally and currently focused on network cost. In fact, until recently, most operators focused almost solely on CAPEX, and it is only over the last decade that total cost of ownership (TCO =CAPEX + OPEX) has started to be considered. As operators have started to consider OPEX, many have realized that OPEX can actually dominate CAPEX over a sufficiently long duration. Energy consumption is becoming an increasingly important component of OPEX. The point this paper makes is that an increased focus on network sustainability (i.e., energy efficiency) can provide dramatic reductions in energy consumption. Energy efficiency, as with many aspects of large-scale construction, is best "built in" as compared with "retro-fitted." The purpose of the GreenMeter paper is to provide a road map for network operators to build-in energy efficiency as well as showing them the potential energy savings that can be attained. Although a focus on CAPEX (and more recently OPEX) has been traditional to date, it is well accepted that, in the future, an increasing number of organizations will move toward "triple bottom line" style accounting. This means modeling, such as provided by the GreenMeter, will be of interest as this trend continues.

II. ENERGY-EFFICIENT CLOUD COMPUTING SERVICES OVER CORE NETWORKS

Cloud computing has now grown into a widely accepted computing paradigm, and its significance is expected to grow even more in the coming years. Virtualization lies at the heart of cloud computing, where the requested services are provisioned, removed, and managed over existing physical infrastructure such as servers, storage, and networks. Our work investigates the energy-efficiency benefits of virtualization and energy-efficient design of cloud computing services in core networks that address the optimal means of distributing content and the replication of VMs. In this, we have combined virtualization, replication, and content distribution for a 2020 network with BAU+GT equipment as well as all the aforementioned techniques of bypass, sleep, MLR, and topology optimization.

We considered the total 2020 traffic according to the traffic strands shown in Fig. 1. As shown in Fig. 2, a typical cloud data center consists of three main parts: servers, internal LAN, and storage. We are not focusing on the energy efficiency inside data centers, however, as this is a subject that has been extensively researched by the Green Grid consortium and others. Cloud data centers are usually co-located with core network nodes to benefit from the large bandwidth offered by such nodes.

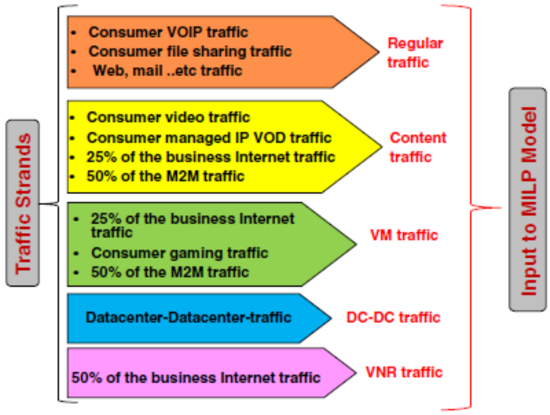

Fig. 1. Traffic strands for distributed cloud for content delivery and network virtualization.

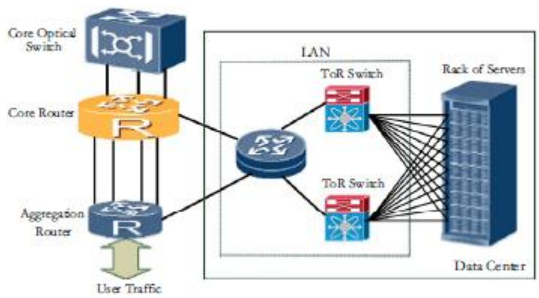

Fig. 2. Cloud data center architecture.

A. Cloud Content Delivery and Virtual Machine Slicing

In cloud content delivery, we serve requests from clients by selecting the optimal number of clouds and their locations in the network so that the total power is minimized. A decision is also made on how to replicate content according to content popularity so that minimum power is consumed when delivering content. Machine virtualization provides an economical solution that enables efficient utilization of physical resources in clouds. Our model optimizes the placement of VMs to minimize energy consumption. In this case, a VM is a logical entity created in response to a service request by one or more users sharing that particular VM. The VM therefore consumes power due to both processing requirements and due to the traffic generated between the VM and the user. We optimize the placement of VMs within the clouds, as demand varies during the day to minimize the network power consumption. The VM placement scheme under consideration is referred to as VM slicing. Under this scheme, incoming requests are distributed among different copies of the same VM to serve a smaller number of users. Each copy of the VM, i.e., a slice, has less CPU requirements compared with that of the original VM. VM slicing is the most energy-efficient approach compared with other VM placement schemes, because slicing does not increase the data center cloud power consumption, allowing the VM slices to be distributed over the network.

B. Network Virtualization

The success of future cloud networks will greatly depend on network virtualization. Here clients are expected to be able to specify both bandwidth and processing requirements for hosted applications and services. The network virtualization ability to allow multiple heterogeneous virtual networks

(VNs) to coexist on one physical platform consolidates resources, which in turn leads to potential energy savings. The network is broken down into multiple VN slices, which are requested by enterprise clients and provisioned by infrastructure providers (InPs). A VN is a logical topology made up of a set of virtual nodes (which can be routers, switches, VMs, etc.) interconnected by virtual links. Enterprise clients send virtual network requests (VNRs) to a cloud infrastructure provider in order to obtain a slice of the network that meets their specific requirements. Our model determines the optimal way of embedding VNRs in the core network with clouds so that the power consumption in the network is minimized.

III. MILP MODEL

The mixed integer linear programming (MILP) model that combines the cloud content delivery model, the virtual machine placement model, and the virtual network embedding model is introduced to collectively design energy-efficient cloud service provisioning in an IP over WDM network. The IP over WDM network incorporates all the techniques that were considered, including optical bypass, MLR, energy-efficient routing, sleep, and physical topology optimization.

Given the client requests for content and VMs and the VNRs, the model responds by selecting the optimal number of clouds and their locations in the network as well as the capability of each cloud so that the network and data center clouds power consumption is minimized. The model decides how to replicate content in the cloud according to its popularity so the minimum power possible is consumed in delivering content. Content has been divided into equally sized popularity groups. A popularity group contains objects of similar popularity. The number and locations of content replicas are optimized based on content popularity. The model also optimizes the placement of VMs as demands vary throughout the day to minimize the total power consumption. In virtual network provisioning, the model efficiently embeds virtual nodes and embeds the bandwidth demands of links associated with VNRs in cloud data centers and in the network, respectively, to minimize the total power consumption.

In the 2020 BAU+GT network, intelligent management of protection resources is introduced where resources are activated only when required, reducing the network power consumption to about the half. Note that protection uses 1 + 1 protection where a protection resource is used for each active resource.

IV. MILP MODEL RESULTS AND ANALYSIS

In this, we present and discuss the power consumption of the AT&T network under the different energy-efficiency techniques investigated in this paper, which represent a 2020 network. For content distribution and VM placement, users are uniformly distributed among the nodes, and the total number of users in the network fluctuates throughout the day between 200,000 and 1,200,000. For the virtual network embedding service, clients are distributed across the entire network. A total of 50 virtual network clients have been considered. The number of clients from each city is dependent on the city's population. The virtual network clients are considered to generate traffic in the network that is equivalent to 50% of the business Internet traffic. The number of virtual nodes per virtual network request (VNR) from a client is uniformly distributed between 1 and 5. Each virtual node has a processing requirement in terms of virtual cores, which are uniformly distributed between 500 and 3000 cores. The requests once accepted into the network stay in the network for a 2 h slot, after which they are torn down and adjusted according to the new arriving demands. A fully provisioned request should be able to provide processing resources in any cloud data center as well as bidirectional traffic resources from the clients' location to any cloud data center. In order to achieve load balancing, virtual nodes belonging to the same VNR are not allowed to be embedded in the same cloud data center. Table I shows the values of the parameters that have been used for the model. The power consumption in data centers due to VMs is considered to be proportional to the number of VM cores used.

TABLE I
PARAMETER VALUES USED IN THE MODEL

Content server capacity (C_{CS})	*1.8 Gbps*
Content server energy per bit (E_{CS})	*211.1 W/Gbps*
Storage power consumption ($P_{(stg)}$)	*4.9 kW*
Storage capacity (Γ_{St}).	*75.6 TB*
Storage utilization (U_{St})	*50%*
Storage and switching redundancy (Red)	*2*
Power consumption per single core of a VM (P_{core})	*11.25 W*
Cloud switch power consumption (P_{csw})	*3.8 kW*
Cloud switch capacity (C_{csw})	*320 Gbps*
Cloud router power consumption (P_{crt})	*5.1 kW*
Cloud router capacity (C_{crt})	*660 Gbps*
Number of popularity groups (G)	*50*
Popularity group size (S_{Pg})	*0.756 TB*
Number of virtual machines for placement (NV)	*1000*
Virtual node consolidation factor (α)	*1*

In the following results, we show the power consumption of individual components that make up the core network. Figure 3 shows the reference case, which is the power consumption of the AT&T network under 2010 traffic, 2010 components, and a 2010 network design, where the network is dimensioned for maximum traffic, and the non-bypass approach is implemented. Components in the network do not adapt their power usage as the traffic varies; hence, the flat trend in Fig. 3. The protection paths are also kept in active state together with the working paths. The major contribution to the total power consumption in 2010 is due to the routers and then followed by transponders.

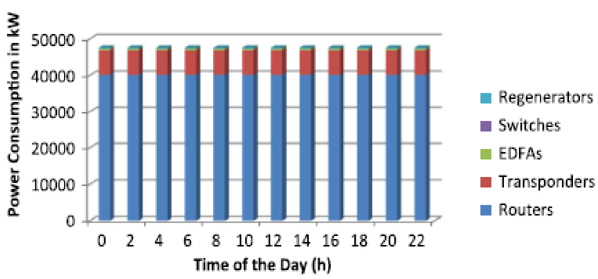

Fig. 3. Power consumption of the original AT&T topology, 2010 components, 40 Gbps, non-bypass, and active protection.

A. 2020 Power Performance With BAU and BAU + GT Components, Idle Protection, Bypass and Sleep Techniques

Figure 4 shows the power consumption in a 2020 network under the BAU scenario. Here, the total traffic in the network has increased. The components' power consumption in the network is also reduced by BAU factors (due to Moore's law). The overall network power consumption in 2020 due to equipment improvement is reduced by a factor of 4.23 when compared with the 2010 network. Note that this reduction and other reductions comparing the 2020 network with the 2010 network reported in this section takes into account that the 2020 traffic increases by a factor of 12 compared with the 2010 traffic (i.e., the energy per bit in 2020 is reduced by a factor of 4.23 compared with that in 2020). The network power consumption considering improved components in 2020 due to GreenTouch initiatives (BAU + GT) is shown in Fig.5. The network power consumption has been reduced by a factor of 20 compared with 2010. The router's power consumption is reduced more than the transponders; as a result, we see an almost equal contribution to the overall power consumption in the network from both transponders and routers.

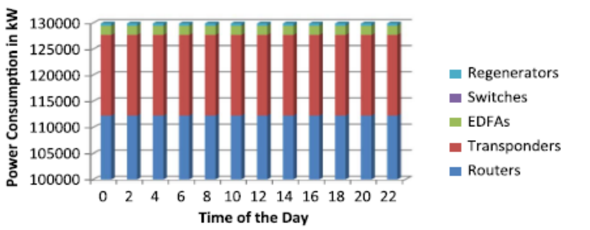

Fig. 4. Power consumption of the original AT&T topology, 2020 BAU components, 40 Gbps, non-bypass, and active protection.

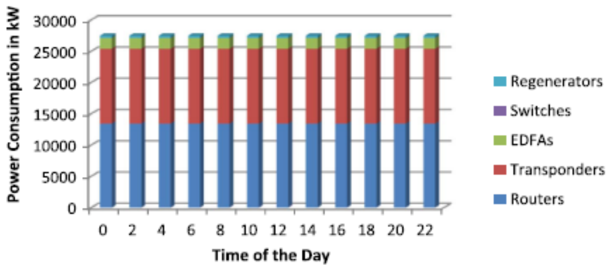

Fig. 5. Power consumption of the original AT&T topology, 2020 BAU + GT components, 40 Gbps, non-bypass, and active protection.

One of the GreenTouch contributions to reducing power consumption in 2020 is to put all the protection paths to sleep while the working paths are active. The savings when using this measure are reflected in Fig. 6. A reduction of 1.96 × is achieved through this measure. Optical bypass, where router ports at intermediate nodes are bypassed using the optical layer, and sleep techniques, where unused router ports, transponders, and regenerators are put to sleep, are implemented in Fig. 7. Therefore, the power consumption follows the traffic variation throughout the day, and a savings of 2.13 × is achieved.

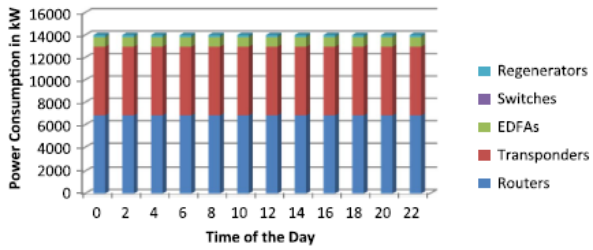

Fig. 6. Power consumption of the original AT&T topology, 2020 BAU + GT components, 40 Gbps, non-bypass, and idle protection.

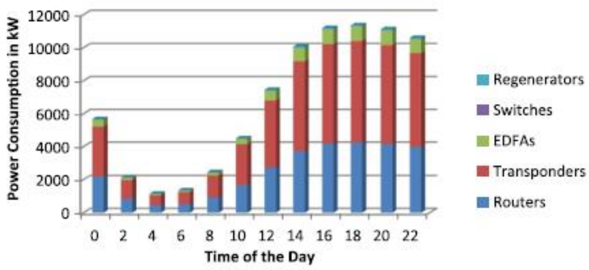

Fig. 7. Power consumption of the original AT&T topology, 2020 BAU + GT components, 40 Gbps, bypass, sleep, and idle protection.

B. 2020 Power Performance With Mixed Line Rates and Topology Optimization

Optical networks with MLR have been proposed as a flexible architecture to efficiently support a heterogeneous range of applications in the core network MLR mitigates the waste of optical bandwidth and creates potential for energy savings. The other consideration is that router ports, transponders, and regenerator power consumption do not scale linearly with data rates. Therefore, MLR uses an optimal combination of router ports, transponders, and regenerators that minimizes the power needed to serve a given demand. For the 2020 network, four line rates: 40 Gbps, 100 Gbps, 400 Gbps, and 1000 Gbps have been considered. Figure 8 shows the network power consumption in 2020 implementing MLR. Routers have benefited from the (observed and extrapolated) saturation behavior that occurs as the data rates increase. Therefore, the router's power consumption has been reduced the most. Transponder power consumption has not shown a significant reduction because, at higher data rates, the transponder consumes a considerable amount of power. This behavior is expected in transponders because, at higher data rates, transponders with long reaches (i.e., in core networks) will have higher order modulation and will operate in the 1550 nm window. This means that the signals will be subject to heavy forward error corrections, which will be incurred during a power consumption penalty. We would therefore expect long-reach high capacity transponder ports to consume more power than short-reach high-capacity router ports. The total network power consumption reduction due to MLR is 1.2 ×. Optimizing the physical topology for power minimization in IP over WDM networks was investigated. We use the same techniques here to optimize the topology of the 2020 AT&T network for optimal power consumption. Figure 9 shows the optimal topology obtained.

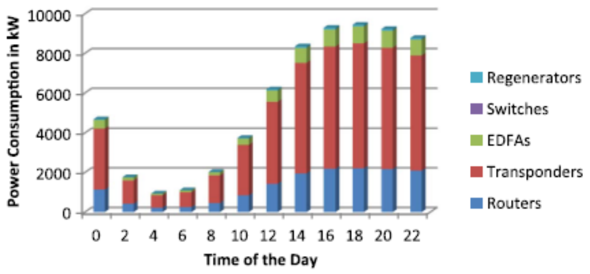

Fig. 8. Power consumption of the original AT&T topology, 2020 BAU +GT components, MLR, bypass, sleep, and idle protection.

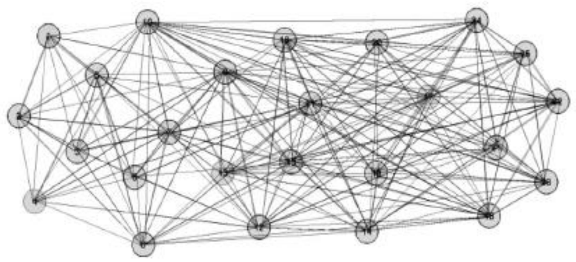

Fig. 9. Optimized 2020 AT&T topology BAU + GT components, MLR, bypass, sleep, and idle protection.

The minimum nodal degree in the optimized topology was kept at 2 to ensure that nodes are not totally isolated from the rest of the network in the case of a single link failure. The optimal topology was obtained without any limit of the total number of links in the network. The optimal topology has a total of 193 links compared with the original topology, which has a total of 54 links. In previous results, when no limit was set on the number of links, the optimal topology was a full mesh. However, in this considering MLR and much longer distances between nodes, which require regeneration. Because the power consumption of a regenerator is about twice the power consumption of a transponder, it becomes more energy efficient for traffic flows to pass through intermediate nodes using optical bypass instead of travelling through a longer direct link where one or more regenerators would be required. Figure 10 shows the power consumption in a 2020 AT&T network with an optimized topology. The network power consumption reduction due to topology optimization is 1.43 ×.

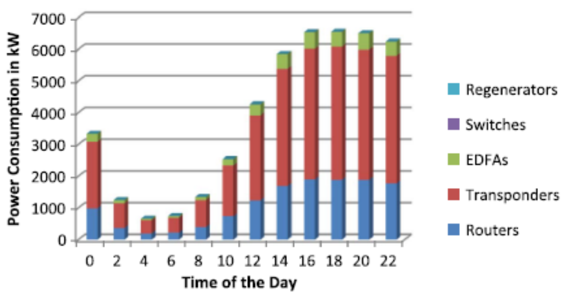

Fig. 10. Power consumption of the optimized AT&T topology, 2020 BAU + GT components, MLR, bypass, sleep, and idle protection.

Figure 11 shows the power consumption of the 2020 AT&T network implementing the different distributed clouds. Distributed clouds reduce the journeys up and down the network to access content and therefore reduce power consumption. We establish the optimal number of clouds to construct where to locate them and which cloud should contain which object based on popularity. In virtual machine slicing, we replicate smaller slices of virtual machines in the network without changing the overall power consumption in servers, thereby reducing the overall power consumption in the network. However, we limit the extent of slicing in order to meet the quality of service thresholds. In network virtualization, we consolidate the use of resources in the network by optimally embedding virtual network nodes and links such that they form a minimal number of hops in the network. Virtual network requests from the same location but from different clients are co-located, and the traffic they generate is groomed together to minimize network power consumption. When all these approaches are implemented, a savings of 2.19 × in network power consumption is achieved. The overall savings in network power consumption considering all the approaches in 2020 compared with the 2010 network are 315 × . Figure 12 shows the network efficiency trend for the 2010 and 2020 network considering the various approaches investigated by GreenTouch. The energy efficiency of the 2010 network is 2774 kbps/W, which translates to 360 nJ/b.

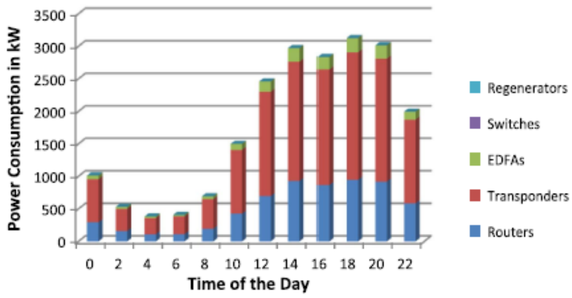

Fig. 11. Power consumption of the optimized AT&T topology, 2020 BAU + GT components, MLR, bypass, sleep, idle protection and distributed cloud for content delivery, VM slicing, and network virtualization.

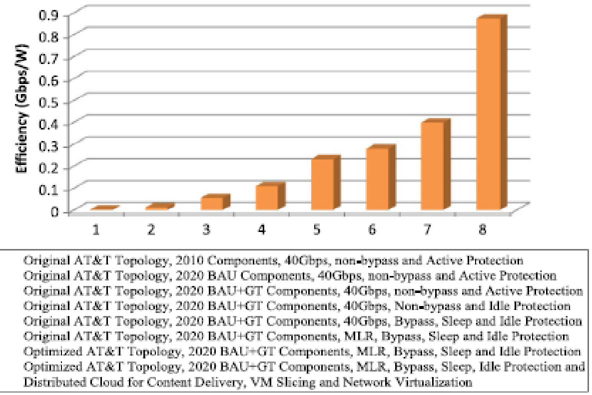

Fig. 12. Energy efficiency of both the 2010 and 2020 AT&T network under different energy-savings techniques

CONCLUSION

In this paper, the energy efficiency of 2020 core networks has been evaluated and compared with networks in 2010 where in the former case consideration is given to different energy-efficiency techniques introduced by the GreenTouch consortium. The energy-efficiency techniques evaluated include (i) the use of improved network components with lower power consumption, (ii) putting idle components into sleep mode, (iii) optically bypassing intermediate routers, (iv) the use of MLR, (v) idle protection, (vi) optimization of the network physical topology, (vii) and the optimization of distributed clouds for content distribution and network equipment virtualization. A MILP model that jointly optimizes IP over WDM core networks considering the aforementioned energy-efficiency measures was developed to accurately determine the energy improvements. The AT&T topology is considered as an example of a continental network topology accommodating group 1 nations' traffic. The projections of the 2020 equipment power consumption are based on two scenarios: a BAU scenario and a BAU plus GreenTouch (BAU + GT) scenario resulting from the technical advances achieved by the GreenTouch consortium. The results show that the energy efficiency of the 2020 network will improve by a factor of 4.23× compared with that of the 2010 network as a result of the BAU reductions in the network equipment power consumption. The 2020 BAU+GT scenario reduces the equipment power consumption by a factor of 20× compared with the 2010 network. A total energy efficiency improvement of 315× is obtained by jointly adopting all the techniques introduced by GreenTouch.

REFERENCES

[1] W. Idler, F. Buchwald, L. Schmalen, E. Lach, R. Braun, G. Böcherer, P. Schulte, and F. Steiner, "Field trial of a 1 Tb/s super-channel network using probabilistically shaped constellations," J. Lightwave Technol., vol. 35, pp. 1399–1406, 2017.

[2] D. S. Millar, L. Galdino, R. Maher, M. Pajovic, T. Koike-Akino, G. Saavedra, D. J. Elson, D. Lavery, K. Shi, M. S. Erkılınc, E. Sillekens, R. I. Killey, B. C. Thomsen, K. Kojima, K. Parsons, and P. Bayvel, "A simplified dual-carrier DP-64QAM 1 Tb/s transceiver," in Optical Fiber Communications Conf. and Exhibition (OFC), Los Angeles, California, 2017, pp. 1–3.

[3] D. S. Millar, R. Maher, D. Lavery, T. Koike-Akino, M. Pajovic, A. Alvarado, M. Paskov, K. Kojima, K. Parsons, B. C. Thomsen, and S. J. Savory, "Design of a 1 Tb/s superchannel coherent receiver," J. Lightwave Technology, vol. 34, pp. 1453– 1463, 2016.

[4] W. Van Heddeghem, F. Idzikowski, F. Musumeci, A. Pattavina, B. Lannoo, D. Colle, and M. Pickavet, "A power consumption sensitivity analysis of circuit-switched versus packet-switched backbone networks," Comput. Netw., vol. 78, pp. 42–56, 2015.

[5] L. Nonde, T. E. H. El-Gorashi, and J. M. H. Elmirghani, "Energy efficient virtual network embedding for cloud networks," J. Lightwave Technol., vol. 33, no. 9, pp. 1828–1849, 2015.

[6] J. M. H. Elmirghani, L. Nonde, A. Q. Lawey, T. E. H. El-Gorashi, M. O. I. Musa, X. Dong, K. Hinton, and T. Klein, "Energy efficiency measures for future core networks," in Optical Fiber Communication Conf. (OFC), Los Angeles, California, Mar. 19–23, 2015.

[7] J. M. H. Elmirghani, T. Klein, K. Hinton, T. E. H. El-Gorashi, A. Q. Lawey, and X. Dong, "GreenTouch GreenMeter core network power consumption models and results," in IEEE OnlineGreencomm, 2014.