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Energy Efficiency Measures for Future Core Networks

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Abstract: We summarize the various techniques developed by the GreenTouch consortium over the past 5 years to minimize core network power consumption. Adopting GreenTouch techniques can potentially improve the energy efficiency by 316x in a 2020 reference network compared to the state of the art in 2010.
OCIS codes: (060.4510) Optical communications; (060.4256) Networks, Network optimization.

1. Introduction

Today the power consumption of communication networks is a significant contributor to the total power demand in many developed countries. Driven by economic, environmental and societal impact, a significant academic and industrial research effort has been focused on reducing the power consumption of communication networks. GreenTouch was a consortium of leading Information and Communications Technology (ICT) experts which included academic, industry and non-governmental organizations, all playing essential roles in technology breakthroughs in energy efficiency. The consortium was formed in 2010 to pursue the ambitious goal of bridging the gap between traffic growth and network energy efficiency improvements. This was achieved in 2015 by delivering a roadmap of architecture specifications and technologies that have the potential to increase network energy efficiency by a factor of 1000 by 2020 compared to 2010 levels. The research areas investigated by GreenTouch include wired access networks, mobile networks, core networks and services, policies and standards.

The white paper [1] published the outcomes of a comprehensive “GreenMeter” research study that investigated the overall impact and energy efficiency obtained from implementing a range of technologies, architectures, devices and protocols developed by GreenTouch. In the (optical) core network these include the use of improved components with lower power consumption, mixed line rates (MLR), energy efficient routing, idle protection, sleep modes, physical topology optimization, virtualization and distributed clouds. Mixed Integer linear Programing (MILP) models were developed to optimise the implementation of these techniques and ascertain the resulting core network power consumption and energy efficiency improvement. The total power consumption was evaluated for a 2010 and 2020 US core network. For the 2010 network we considered the traffic in 2010 along with the most energy-efficient commercially available equipment at that time. The 2020 network was based on projections of the traffic to 2020 and the reductions in the equipment power consumption expected by 2020. The projections of the 2020 equipment power consumption considered two scenarios: 1) a business as usual (BAU) scenario and 2) BAU+GreenTouch (GT) scenario where the technical advances achieved by GreenTouch accelerated the reduction in equipment power consumption. This paper summarizes the GreenMeter results and highlights the promising energy savings that can be achieved by implementing the above techniques which are proposed as energy efficiency measures for 2020 core networks.

2. Evaluation methodology

We considered the power consumption of the following network elements in the IP/WDM network; (i) Routers (ii) Transponders (iii) Regenerators (iv) Erbium Doped Fiber Amplifiers (EDFAs) and (v) Optical Switches. The BAU equipment power consumption is obtained by only applying expected energy efficiency improvements due to advanced CMOS technologies. BAU+GT equipment energy efficiency comes from implementing various GreenTouch techniques such as optical interconnects and saving processing power by matching / adapting processor capability to packet sizes in router ports. GreenTouch introduced dynamic voltage and frequency scaling in transponders DSPs [2, 3]. Regenerators are expected to follow the same trend as transponders. The reduction in EDFAs power consumption is expected to follow Moore’s law for the EDFA electronics with the EDFA optical components having lower impact on power consumption reduction. Optical switches will stay the same in a BAU network in 2020 but reduction in power consumption of the order of 10x are expected in a BAU+GT network according to the work in [4]. Table 1 shows the power consumption values of various components that have been used in the MILP model in 2010 and 2020 BAU and BAU+GT.

Table 1 Power consumption values

Device	2010 Power Consumption	2020 Power Consumption	
		BAU	BAU+GT
Router Port 40 Gb/s	825 W	178.2 W	21.3 W
Router Port 100 Gb/s	*Not widely deployed in the field*	309.3 W	39.2 W
Router Port 400 Gb/s	*Not widely deployed in the field*	367.8 W	46.7 W
Router Port 1 Tb/s	*Not widely deployed in the field*	425.1 W	53.9 W
Transponder 40 Gb/s	167 W [5] Reach 2500 km [6]	35.7 W Reach 2500 km	27.6 W Reach 2500 km
Transponder 100 Gb/s	*Not widely deployed in the field*	110.9 W Reach 1200 km [5]	86 W Reach 1200 km
Transponder 400 Gb/s	*Not widely deployed in the field*	428 W Reach 400 km	332.6 W Reach 400 km
Transponder 1 Tb/s	*Not widely deployed in the field*	1032.6 W Reach 350 km	801.3 W Reach 350 km
Regenerators 40 Gb/s	334 W [5] Reach 2500 km [5]	71.4 W Reach 2500 km	55.2 W Reach 2500 km
Regenerators 100 Gb/s	*Not widely deployed in the field*	221.8 W Reach 1200 km [5]	172 W Reach 1200 km
Regenerators 400 Gb/s	*Not widely deployed in the field*	857.4 W Reach 400 km	665.2 W Reach 400 km
Regenerators 1 Tb/s	*Not widely deployed in the field*	2065.2 W Reach 350 km	1602.6 W Reach 350 km
EDFA	55 W [7]	15.3 W	15.3 W
Optical Switch	85 W [8]	85 W	8.5 W

Using Cisco traffic growth forecasts for the dominant types of Internet traffic [9], we estimated the 2020 traffic over a diurnal cycle and spread it across the network geography using a gravity model and accounting for time zones. Figure 1 shows the results for a US based network. The 2020 traffic projection has a 12 fold increase compared to 2010 traffic. We have also considered data center to data center (DC-DC) traffic that will be generated due to the creation of distributed cloud data centers.

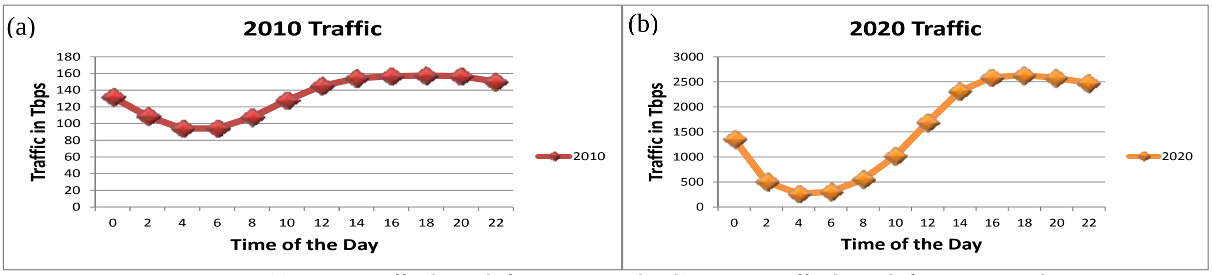

Figure 1(a) Average traffic demands for 2010 networks; (b) Average traffic demands for 2010 networks

3. MILP model results and analysis

Figure 2(a) shows the reference case which is the power consumption of the core US network evaluated for 2010. Components in the network do not adapt their power usage as the traffic varies, hence the flat power consumption in Figure 2(a). The protection paths are also kept in an active state together with the working paths.

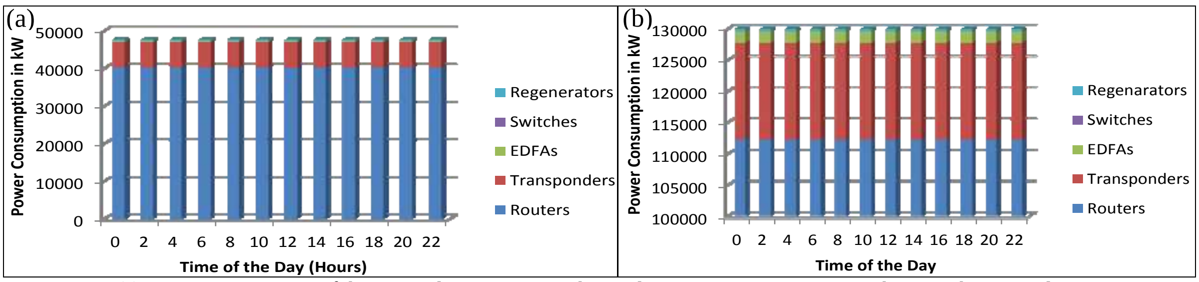

Figure 2(a) Power Consumption of the Original core US network Topology, 2010 Components, 40Gbps, non-bypass and Active Protection; (b) Power Consumption of the Original core US network Topology, 2020 BAU Components, 40Gbps, non-bypass and Active Protection

Figure 2(b) shows network power consumption in 2020 under BAU. Here, the total traffic in the network has increased to the levels shown in Figure 1(b). The components' power consumption in the network have been reduced by BAU factors (due to Moore's law). The overall network power consumption reduction in 2020 due to equipment improvement is 4.23x that of the 2010 network.

For (BAU+GT), the reduction in equipment power consumption in 2020 due to the GreenTouch initiatives is 20x compared to 2010. Further GreenTouch contributions to reduce the power consumption in 2020 include placing all the protection paths into sleep mode while the working paths are active and using optical bypass and equipment sleep mode. In these approaches, unused router ports, transponders and regenerators are put to sleep and router ports at intermediate nodes are bypassed using the optical layer. Consequently, the power consumption follows the traffic diurnal cycle throughout the day. A saving of 2.13x is achieved as a result of these measures. Moreover, optical networks with mixed line rates (MLR) were considered [10, 11], where an optimised combination of data rates in routers, transponders and regenerators was employed to minimize the power required to serve a given traffic demand. For the 2020 network, four line rates; 40Gbps, 100Gbps, 400Gbps and 1000Gbps were used. The total network power consumption reduction due to MLR was 1.2x. In addition, optimizing the physical topology for power minimization in IP over WDM networks was investigated in [12], and considered in this work. The improvement due to topology optimization is 1.43x.

Our work in [13], investigated the energy efficiency benefits of virtualization and our work in [14], investigated the energy efficient design of cloud computing services in core networks addressing the optimal way of distributing content and the replication of virtual machines. Distributed clouds reduce the paths through the network to access content and therefore reduce power consumption. In virtual machine slicing, incoming requests are distributed among different copies of the same VM to serve a smaller number of users as proposed by the authors in [15], without changing the overall power consumption in servers, thereby reducing the overall power consumption of the network. In network virtualization, we consolidate the use of resources in the network by optimally embedding virtual network nodes and links such that they form minimal number of hops in the network. When all these approaches are implemented a saving of 2.19x is achieved. 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. The overall network energy efficiency improvement considering all the approaches in 2020 compared to the 2010 network is 316x Figure 4 shows the network energy efficiency for the 2010 and 2020 network considering the various approaches investigated by GreenTouch.

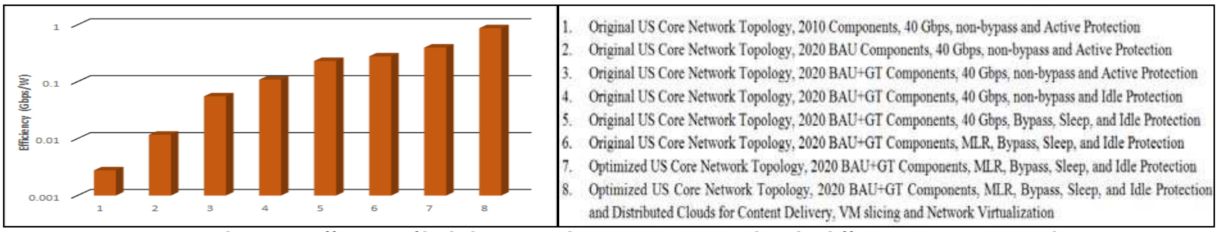

Figure 4 The energy efficiency of both the 2010 and 2020 US core network under different energy savings techniques

To assess the quality of the MILP results obtained, we also developed closed form expressions and bounds for the power consumption of core networks for the different scenarios investigated in this work. The analytical results were close to those obtained from the MILP models. We further introduced an experimental demonstration that illustrates the feasibility of energy efficient content distribution in IP over WDM networks. The demonstration switches content delivery from a central server to distributed servers, located near end users, and ensures the seamless delivery of the content while minimizing the network power consumption.

4. Conclusions

Substantial energy gains that can be achieved through the adoption of a range of techniques developed by GreenTouch have been reported. A typical 2010 network was used as the reference in determining the energy savings achieved through the introduction of the new techniques. The joint optimization of idle protection, sleep, bypass, MLR, network topology, distributed clouds for content delivery, virtual machine slicing and network virtualization resulted in an overall energy efficiency improvement of 316x compared to the 2010 network.

5. Acknowledgments

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