A Review of Energy Efficiency Considerations in Optical Backbone Supported Clouds

Bakhe Nleya
Department of Electronic Engineering
Faculty of Engineering, DUT
bakhen@dut.ac.za

Philani Khumalo
Department of Electronic Engineering
Faculty of Engineering, DUT
KhumaloPK@elec.durban.gov.za

***Abstract*—Ever arising energy demands as well as the associated effects such as adverse climate changes are leading to an increased interest in energy efficiency which by enlarge can only be achieved by the incorporation of Information and Communication Technology (ICT) technologies in legacy and present power grid systems thus transforming them into smart grids. ICT is responsible for a significant total energy consumption globally and hence the need to implement measures and policies aimed at reducing it. Gradually electrical energy (power) is becoming key to the normal everyday life of humanity as well as for the services provisioned by ICTs. Smart Grids concepts such ass distributed generation, dynamic pricing, and demand/response management, are impacting the operation of ICT services such as, clouds and data centers.**

In this paper, we overview smart grid-driven approaches in energy-efficient communications and data centers and clouds, and the interaction between smart grid and information and communication infrastructures. We provide smart grid-driven approaches in energy-efficient communication systems we pay attention to we analyze the energy efficiency of an all-optical network support backbone for smart grids.

Keywords—energy efficiency, optical burst switching, transparent networks, access networks, energy-aware networks, data networks, clouds

I. Introduction

Current and future Smart grids will incorporate advanced communication, sensing, as well as control capabilities in the power grid's operation, to enhance reliability efficiency, security as well as reduced emissions [1]. Such functionalities/capabilities were limited on legacy grids but, however continued advances in ICT technologies have triggered modernization of both all key elements of the power grid. As such Smart grids have increased legacy power systems efficiencies by incorporating renewable energy sources in to the grid as well as employing smart demand management and furthermore by adopting measures to curb transmission power losses on the distribution segments of the power grids. lines [1], [2]. Key to all this is energy efficient communications. In terms of communication coverage and functionality, a fully fledged smart grid is composed of s three domains as follows: Smart Grid Wide Area Network (SG-WAN), Smart Grid Home Area Network (SG-HAN) and a Smart Grid Neighborhood Area Network (SG-NAN) [3]. Typically, a SG-HAN is confined to a single residential house and typically serving a few house-hold smart appliances as well as a smart meter. A SG-NAN houses a few households all typically fed from the same transformer. SG-WANs interconnect SG-HANs and SG-NANs. The smart meters relay mostly billing data from the residential households using the available Advanced Metering Infrastructure (AMI) and sends it to the utility operator via the SG-NANs. For facilitating monitoring as well as control of equipment in the field a separate network known as a Smart Grid Field Area Network (SG-FAN) is created. In practice, the SG-FAN and SG-NAN are quite similar and hence utilize similar communication technologies [4].

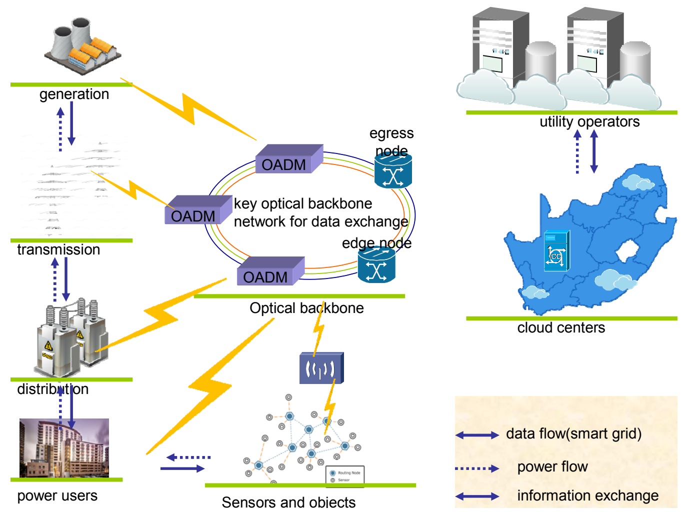

Figure 1. Smart Grid and support Network infrastructure.

The ever-increasing volumes of bandwidth-intensive applications and services are directly driving the requirement for energy efficient enabling networking infrastructures to support the resultant extremely high bandwidths and diverse data traffic flows. Information infrastructure along with communication infrastructure is a significant consumer of electricity in a smart grid and this attributed to by the presence of cloud computing and data centers and hence associated voluminous data exchanges. Sources of this data include [4]:

Information systems: utility information systems will generally utilize data from Grid related components such as substations, and consumers to extract critical information about the general state of the distribution network, equipments, energy consumed, the consumption modes, etc. This will be used for improving the design and operation of the grid. Utility information typically includes, Supervisory Control and Data Acquisition (SCADA), Geographic Information System (GIS. Customer Information System (CIS), Advanced Metering Infrastructure (AMI) and Meter Data Management System (MDMS), Demand Response Management System (DRMS) and Outage Management System (OMS.

Advanced metering infrastructure. This is a platform for facilitating smart metering.

Supervisory control and data acquisition(SCADA): Its main function is that of acquiring, communicating as well as presentation of data and control information in order to better automation, as well as efficiency. It generally facilitates optimal energy delivery by using programmable controls as well as facilitating, multi-protocol support.

Outage management system: These help in enhancing smart grid customers' satisfaction by voluntarily discovering, locating and resolving power outages in a very efficient and short time.

Geographic information system(GIS): The system is primordial for utilities as it visualizing and mapping points of interests in the smart grid. As such it can is a technology aiming at providing the power utility with a global vision of users, generators and power lines position etc.

Customer information system: The Customer Information System (CIS) comes in order to develop the relationship between utilities and customers using every customer interaction. CIS helps utilities to deliver their services efficiently, to automate periodic tasks and to understand customers requirements and how each customer is connected to the grid.

Demand response management system. This system brings several benefits such as reduce energy costs, improve stability and security of the smart grid. It gives the utilities the ability to create automated, integrated, and flexible platforms to manage demand response solutions in an efficient and smart manner.

The resulting voluminous aggregated data requires a backbone with a matching capacity.

As such, dense wavelength division multiplexed (DWDM) optical backbone networks have enabled increased data transmission capacities to terabits per second ranges, as well as coupling with optical burst switching (OBS) paradigm to address the matching switching capabilities [1]. At transmission level, received data packets are aggregated and assembled into optical burst units generally referred to as data bursts by edge nodes before being transmitted into the core network, thus in the process reducing switching capacity requirements. A powerful driver for this work lies in addressing the power consumption of communication infrastructures in smart grids. The energy bottleneck has long been a key driving force for developing optical interconnects in traditional high-performance computing systems, and is now becoming a limiting factor in telecommunication networks.

Summarily, an OBS backbone network consists of edge and core nodes interconnected via DWDM optical fibre links. It primarily interconnects, residential access, home networks (wired and wireless), core, metro and data centers. Today, most advanced metro core rings consist of Optical Add Drop Multiplexers (OADM) and Optical Cross Connects (OXCs). This survey devotes greater attention to surveying energy efficiency in the backbone as well as its traffic tributaries, mainly the access, and metro networks which when aggregated are expected to surpass the zettabyte threshold soon [2]. Nonetheless, by comparison, the core backbone sections of this supporting network are likely to expend more power than that of the access and metro networks [3]. Presently, residential and metro (wired and wireless) access networks dominate power consumption. However, the high aggregated traffic volumes in the optical backbone network will lead to higher power consumption, thus likely to exceed energy consumption of the access level networks [3], [4].

Table 1. Power requirements. (Adapted from [4]).

network Domain	device	capacity	power consumption
backbone network	core router	10Gbps	25-68.5kW
	amplifier	l fiber	46-106W
	regenerator	per lightpath	6-80W
	Converter	per lightpath	0.5-2W
	WDM transponder	40GBs	60-100W
	OXC	2-degree	25-68.5W
metro network	Edge switch (router)	160GBs	4.21kW
	OADM	N/A	450W
	Ethernet switch	720Gbs	3.21kW
	gateway	8Gbps	1.1kW
	Edge LAN Switch	48000Mbps	100-300W
access network	10/100 Hub	1200Mbps	12-35W
	WAP	54Mbps	8-13W
	OLT	1GBs	100W
	telephony sub switch	20000 subscribers	6kW
	ONU	1GBs	5W
household network	modem	up to 300Mbps	5.7W
	router	up to 500Mbps	5.7W
	access point	_	1.9W
	switch	up to 500Mbs	2.6W
	ONTs	up to 600Mbps	16.2W

Our objective in this paper is to provide an overview on energy-efficient techniques employed in present and future optical backbone networks which can sustain ever surging traffic levels with reduced energy consumption. We will generally discuss these mainly under the following general categories namely, designing power efficient end-devices, network redesign i.e. designing power-efficient, traffic engineering, power-aware networking, adaptive operation and energy efficient protection networking.

II. ENERGY EFFICIENT NETWORKING EFFORTS

Due to the purposeful global campaigns aimed at mitigating factors that cause environmental pollution, the ICT/telecommunication sectors joined the bandwagon in the quest to protect our environment by adopting initiatives that are geared towards energy-efficient communication infrastructures. In addition, the current departure from the traditional technologies and strategies does not only result in the reduction of harmful gases released into the environment, but also lead to substantially low OPEX for network operators. As previously stated, a significant number of scholars have focused their attention in conducting research in this important niche area to come up with energy-efficient solutions for backbone communication networks. In this review, we have categorized the main energy-efficient networking techniques used existing in various literatures into five main approaches, namely, network redesign, traffic engineering, power-aware networking, adaptive operation and energy efficiency network protection.

A. Network Re-Design

Generally, the energy usage of the core network can be significantly lowered by redesigning the physical links and the core nodes. Traditionally, the physical links rely on optical technologies, whereas the core nodes have essentially been based on electronic technology [4]. Since electronic devices are slower than their optical components, there is a need to gradually replace most electronic switching components by optical switching devices [4], [5]. Through the technique of "multiple-shelves", the speed of an electronic core router can be improved, but at the expense of increased energy consumption [5]. However, the replacement of a core electronic router by an OXC provides opportunities for very fast switching due to the elimination of bottlenecks that arise due to slow electronic processing. In addition, potential energy savings will be realized as well [5]. Table 1 in the previous section shows some vital information about various core network devices and their respective energy consumptions [4]. By redesigning the physical topology of the core networks via the optimization of available links, massive energy savings may also be realized [4]. Since the CAPEX of an optical core network is mainly determined by link deployment costs, it is therefore prudent and logical to interconnect core nodes through as fewer number of links as is possible. However, it is crucial to strike a balance between the number of links, performance (reliability) as well as and energy consumption as some topologies may contain fewer links but end up consuming significantly large amounts of energy and at the same time degrading reliability

Figure 2 illustrates two different topologies designed to reduce cost and energy consumption respectively, but at the same time maintaining reliability.

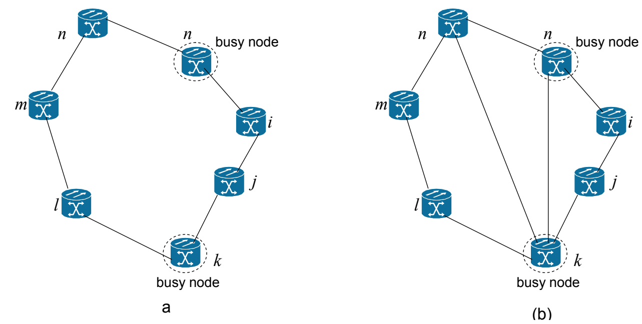

Figure 2. Networking topologies: (a) ring and (b) mesh [6].

The topology in (a) costs less as it has relatively fewer links. However, the topology consumes more power as communication between selected nodes involves many links. Overall it follows that optimizing the physical topology is critical in balancing power consumption at reduced levels, cost as well as reliability, and as such an optimized network topology accommodates traffic using fewer network devices.

BI. Traffic Engineering

Another way of reducing energy consumption of core networks is to limit the use of network devices such as ports and fibres, by utilizing traffic grooming techniques. [7], [8]. If several low-granularity traffic movement is aggregated into a few, high-granularity traffic flow, the number of wavelengths that traverse the core network will be drastically reduced and this leads to a reduction in demand of network resources [7], [9].

C. Energy-Aware Networking

In general, network elements in core networks are configured to support peak-period traffic and thus during off-peak periods, significant amounts of energy are unwisely wasted since most devices will not be performing any functions [8], [9], [10]. Due to the increased sizes of current networks, and hence several energy consuming devices, it has become very critical and important to switch off some devices during low traffic periods, and this in turn calls for the adjustment of routing schemes to be fully optimized to become energy-efficient.

D. Load-Adaptive Operation

Previous studies on the rated power consumption values of network devices in [7] suggest that low capacity devices (or devices running at low operational speeds) expend less power. However, high-capacity devices consume less power per bit of transmitted traffic and, thus, are more energy efficient [7]. To attain higher energy efficiency, or rather low-power consumption, it is preferable to deploy a minimum number of network devices with capacity that matches the actual traffic speed.

.

III CONCLUSIONS

Globally ICTs are significant energy consumer as well as GreenHouse Gas (GHG) emitter. The clouds and data centers expend large energy volumes such that consequently, their OPEX is also surging with increasing electricity tariffs and associated carbon emission taxes. This has prompted research into techniques that enhance energy efficiency of ICTs. Applying existing smart grid-driven techniques together with traditional ones can lead to OPEX reductions. Measures such as distributed generation, dynamic pricing schemes, demand management, monitoring of faults and disturbances can be effectively utilized to minimize both energy consumption and losses and consequently emissions of ICTs.

In this survey paper, we have surveyed techniques employed in present and future optical backbone networks which can sustain ever surging traffic levels with reduced energy consumption.

Focusing more attention to green data centers and clouds (i.e. repositories for the storage, management, and dissemination of data in which the mechanical, lighting, electrical and computer systems are designed for maximum energy efficiency and minimum environmental impact) is required. Well known techniques and measures include: such as usage of alternative energy technologies (photovoltaics, heat pumps, and evaporative cooling); minimization of footprints of the buildings; usage of low-emission building materials, carpets and paints; waste recycling; Installation of catalytic converters on backup generators; sustainable landscaping; usage of hybrid or electric company vehicles.

REFERENCES

[1] Esther Le Rouzic, Raluca-Maria Indre. TREND Big Picture on Energy-Efficient Backbone Networks. **2**4th Tyrrhenian International Workshop on Digital Communicatiobns. Genoa,,. 23-25 Sept. 2013.

[2] M. Nishan Dharmaweera, Rajendran Parthiban, and Y. Ahmet ¸Sekercioglu. Toward a Power-Efficient Backbone Network. The State of Research. IEEE Communication Surveys & Tutorials, Volume . 17, Number 1, First Quarter, 2015.

[3] Jingcheng Gao. Yang Xiao, Jing Liu, Wei Liang, C.L. Philip Chen. A survey of communication/networking in Smart Grids. Future Generation ,Computer Systems. Volume 28 Issue 2, February, 2012.

[4] Weixiao Meng ; Ruofei Ma ; Hsiao-Hwa Chen. Smart grid neighborhood area networks: a survey.IEEE Network > Volume: 28 Issue: 1.

[5] Yi Zhang, Pulak Chowdhury, Massimo Tornatore, and Biswanath Mukherjee. Energy Efficiency in Telecom Optical Networks. IEEE Communications Surveys & Tutorials, Volume 12, Number 4, Fourth Quarter, 2010.

[6] A. Klekamp, U. Gebhard, and F. Ilchmann, “Energy and Cost Efficiency of Adaptive and Mixed-Line-Rate IP over DWDM Networks,” Journal of Lightwave Technology, vol. 30, no. 2, 2012.

[7] ITU Symposia on ICTs and Climate change,” http://www.itu.int/ ITU-T/worksem/climatechange/index.html, 2009.

[8] Zhang, Yongli Zhao, Xiaosong Yu, Jie Zhang, Mei Song, Yuefeng Ji, and Biswanath Mukherjee. Energy-Efficient Traffic Grooming in Sliceable-Transponder-Equipped IP-Over-Elastic Optical Networks. Journal of Optical Communications and Networking, Volume 7, Number 1, 2015

[9] L. Chiaraviglio, M. Mellia, and F. Neri, “Energy-Aware Networks: Reducing Power Consumption by Switching off Network Elements,” GTTI’08, Rome, Italy, May 2008.

[10] Melike Erol-kantarci and Hussein T. Mouftah. Energy-Efficient Information and Communication Infrastructures in the Smart Grid: A Survey on Interactions and Open Issues. IEEE Communication surveys &Tutorials. Volume 17. Number 1, First Quarter, 2015.

[11] Houda Daki,Asmaa El annani,Abdelhak Aqqal,Abdelfattah Haidine and Aziz Dahbi. Big Data management in smart grid: concepts, requirements and implementation. Journal of Big Data20174:13.