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Efficient Energy Management in Networking

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Abstract: *In the last couple of decades, we have witnessed major technological changes that have transformed the way we live, work, and interact with one another. One of the major technology facilitator in charge of for this remarkable transformation in our global society is the deployment and use of Information and Communication Technology (ICT) equipment. In fact, today with the current pandemic going on ICT has become highly integrated in our society that includes the dependence on ICT of various sectors, such as business, transportation, education, and the economy to the point that we now almost completely depend on it. In the last few years, the energy consumption resulting from the usage of ICT equipment and its impact on the environment have resulted in a lot of interests among researchers, designers, manufacturers, policy makers, and educators. Hence energy efficiency has become important bar that is being increasingly used to evaluate energy consumption of devices, hardware and various networking architectures, systems, and communication protocols. I will cover the same and present some of the motivations driving the need for energy-efficient communications in this paper. There have been a lot of approaches to minimize energy consumption by communication devices, protocols, networks, end-user systems, and data centers and I will describe and discuss some of the recent techniques and solutions that have been proposed to minimize energy consumption, also look to the future of networking from a new angle, where energy efficiency and environmental concerns are viewed as fundamental design criteria and forces that need to be harnessed to continually create more powerful networking equipment.*

Keywords: Information and Communication Technology, energy-efficient networking, communication protocols

I. Introduction

Over the last two decades, we have witnessed an explosive growth in the use of Information and Communication Technologies equipment in all spheres of life that include the industrial, commercial, and residential sectors. ICTs have now become an essential part of our daily lives and our society has become heavily dependent on it. In the early days when ICT was developing, a major focus of ICT equipment was on performance and cost. Little attention was given to the power consumed by ICTs and their impact on the environment.

New trends such as rising costs of electricity, resource constraints, and increasing emissions of carbon dioxide CO_2—a major contributor to global warming, are changing this focus making these trends global issues for governments and businesses. It is more than likely that energy consumption and carbon emissions will continue to increase in coming years. According to the SMART 2020 study, CO_2 emissions from ICT are increasing at a rate of 6% per year and with such a growth rate they could represent 12% of worldwide emissions by end of 2020 itself [1].To address this issue, it is crucial that we seek to improve and maintain the performance of ICTs while minimizing their energy consumption and their carbon footprint. ICT energy efficiency is not just about the amount of energy consumed by various ICT equipment and operations alone.A comprehensive energy-efficient ICT solution needs to take into account the entire product life cycle spanning from manufacturing to operation to disposal and recycling of end-of-life products. In this paper, I have focus primarily on the energy consumed by current commodity networking technologies, such as wired/wireless networks, communication protocols, end-user devices, and communication protocols and their environmental impact in terms of CO_2 emissions because these are the most widely used and deployed worldwide as part of the Internet infrastructure.

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In this paper, the scope of this work is restricted to energy-efficient schemes and strategies that are closely related to commodity networking technologies and devices that are currently most widely deployed and used within ICTs. Figure 1 shows some of the major networking components and technologies i.eexcluding wireless sensor networks and ad-hoc networks, that we focus on in this work. Energy-efficient issues that address the entire product life cycle like material extraction, production, use, transport, and waste management of ICT equipment and ICT hardware components like processors, memory, etc. are beyond the scope of this paper.

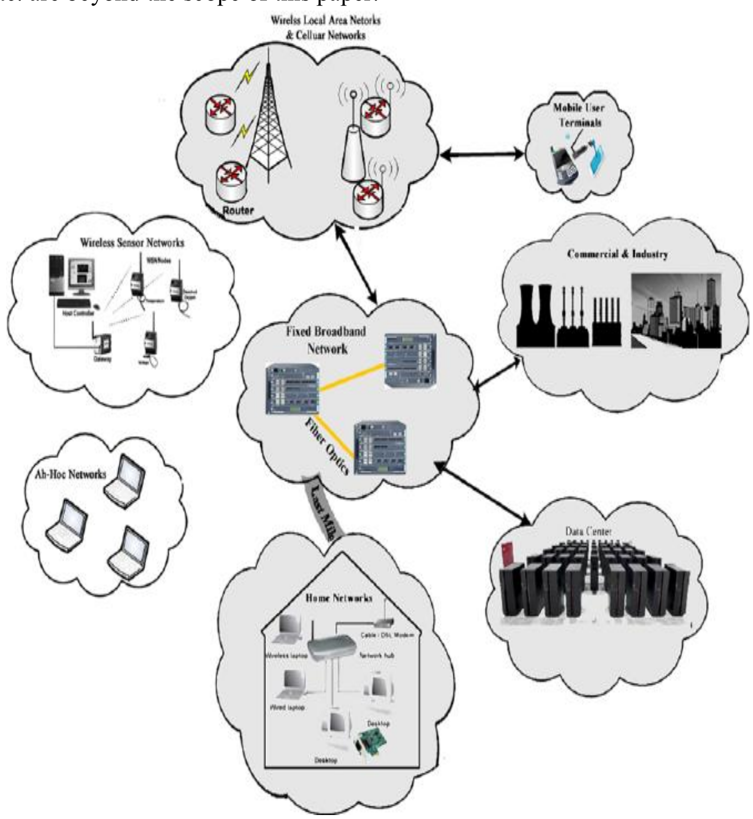

Fig. 1: Major networking areas of focus in this work with wireless sensor networks and ad-hoc networks excluded [2]

The deployment and adoption of a wide variety of next generation wired/wireless and cellular networking technologies are causing a dramatic increase in the energy consumption. Another dominant factor that is exacerbating the energy consumption in the telecommunication sector is the continued growth of the Internet which is being fueled by the growing number of different types of networks, the number of Internet users using various types of mobile devices some sort of handheld device such as a smartphone, personal computers i.edesktops and laptops, etc. and the emergence of high bandwidth applications such as video conferencing, video on-demand, remote visualization, video game consoles e.gXbox and PlayStation, high-definition TV, etc. all of which contribute to increased energy consumption.

In developing nations such as our country India, the predicted rise in energy consumption by almost 30% by 2014 [3] stems primarily from the growing computing infrastructure such as personal computers, monitors, and mobile devices. Similar trends exist with other telecommunication and service providers in other countries to cope with increasing traffic demand and the ability to support emerging services. User mobility and the expectation of users to access information anywhere, anytime, from any device also require the availability of mobile communication networks and infrastructures to support such communications.

It is therefore in the interest of network designers, telecommunication equipment manufacturers, and service providers to build novel networking technologies, wireless transmission techniques, and network architectures and protocols that can scale cost-effectively not only in terms of their performances but are also highly energy efficient during their operations in order to lower their operational costs

II. Energy-Efficient Networking Approaches

Research on energy-efficient networking has been going on for several years. With the growth of the Internet including wired networks and the emergence of wireless networks such as wireless sensor networks, multi-hop networks, mesh networks, ad-hoc networks, many studies have explored the topic of energy-efficiency of these networks, and protocols and applications running over them. Various energy-related issues have been thoroughly investigated covering a wide range of topics like routing, cross-layer designs, coverage protocols, spectrum allocation, Media Access Control (MAC) protocols, resource allocation, scheduling, etc. The goal of this section is to present some of the most recent advances that have been made specifically to improve the energy-efficiency of commodity-based networks e.g., Ethernet, Wireless Local Area Networks (WLANs), cellular networks rather than discussing related works for specialized networking technologies e.g., sensor networks, ad-hoc networks, etc. (As shown in Fig. 1).

2.1 Energy Management for Network Equipment

Ethernet is the most popular wired technology for Local Area Networks (LANs) with over three billion network interfaces and millions of users worldwide. It is widely used in residential, commercial, and industrial sectors. Today, almost any desktop, laptop, or server manufactured has one or more Ethernet network adapters. Recently, many home appliances are also being equipped with Ethernet network interfaces. Ethernet data transmission rates have been improving over the years from 10 Mbits/s to the latest 10 Gigabit Ethernet 10 GbE technology that can support 10 Gbits/s. Higher data rates supported by recent Ethernet network adapters consume a much higher amount of power.

Over the last five years, networking researchers and designers have been showing a lot of interests to improve the energy efficiency of Ethernet network technology. Their efforts led to the development of the IEEE 802.3az Energy Efficient Ethernet (EEE) standard that was approved in 2010. The basic enhancement made by the EEE is the introduction of the Low Power Idle (LPI) concept. For high-speed Ethernet 100 Mbits/s and above, a sender continuously transmits an idle signal that is used to maintain the alignment between the sender and the receiver even when there is no data to transmit. The requirement to transmit this idle signal causes different parts of the transceiver of the network adapter to remain active and consume a significant amount of energy. The proposed LPI concept distinguishes between long periods of inactivity during which no signal is transmitted and saves energy and short periods of activity during which a signal is transmitted to refresh the receiver state. At least 50% energy saving is made over the traditional approach of using an idle signal [4].

Efforts to deploy energy-efficient network products also have recently been initiated by various networking equipment manufacturers such as D-link through their D-link Green Technology initiative. For instance, the D-Link's Power Line Ethernet adapter saves energy by reducing the power delivered to it when it is not used. D-Link released their 16-port Managed Gigabit Switch that has the capability of automatically monitoring the status of the switch and minimizes power consumption by reducing the power delivered to ports that are not linked. D-link reports a maximum of 44% power savings with their energy efficient switches. Another feature of this switch is the inclusion of a smart fan equipped with heat sensors that can cause the fan to be switched on if the temperature of the switch increases beyond some level.

2.2 Network Connecting Devices—Routers and Switches

In addition to the dramatic increase in the bandwidth of communication links for wired networks, another significant development over the last decade has been in the area of routers and switches that are widely used to connect different types of high-speed networks that make up the Internet today. Unfortunately, the electronic components of these switches and routers are beginning to reach their physical limits primarily because of factors, such as maximum clock rate, maximum number of gates, and other hardware design limitations. The power density of the routers continues to increase, and at the same time, their power consumption also continues to rise with each new generation of switches and routers dissipating more heat than the previous generation. Many energy-saving optimization techniques for devices like routers, switches, etc. connecting networks are mostly based on (a) exploiting idle states when no operations are being performed by putting some switch/router components in low-power modes or turned off completely, (b) clocking the hardware at a lower speed, (c) adjusting the trade-offs between performance and energy during active periods e.g., by reducing the link layer rate when the traffic generated is low. Several power management solutions in connecting devices have recently been proposed that use a variation of these techniques or some hybrid combinations of them. It is worthwhile mentioning that hardware designers have also been investigating energy-efficient on-chip communication architectures and dynamic voltage and frequency scalinga power management technique to reduce the voltage based on the frequency of the processor clock techniques for several years and many solutions have been proposed.

2.3 Energy-Efficient Communication Protocols

There are two major characteristics of a protocol that can affect its energy-efficiency. The first is the overheads incurred to transmit the same amount of data. Higher protocol overheads make a protocol less energy efficient. The second major factor that can affect the energy efficiency of a protocol is the time overhead. The longer the time it takes to send data, the longer a radio interface should be active increasing the energy consumption. Energy-efficient techniques that have been recently proposed primarily over commodity for wired and wireless local area networks is the popular Transmission Control Protocol and the Internet Protocol (TCP/IP).

The rapid proliferation of TCP/IP-based applications has made TCP the de facto transport protocol for reliable communications over IP-based wired, wireless, and hybrid wired/wireless networks. Mobile users are becoming increasingly dependent on portable devices such as smart phones, laptops, cell phone, handheld many of which are powered by batteries. Many research works [5, 6] have been undertaken in the past to improve the performance of TCP over wired, wireless, including mobile wireless networks, heterogeneous wireless, and heterogeneous wired/wireless networks. Most of the proposed approaches use one of the following techniques: link layer, end-to-end, split by splitting a TCP connection into two: (a) one between the mobile host and the base station and the other between the based station and (b) the fixed host, cross-layer schemes, and various types of modifications to TCP congestion control algorithm. Most of them have focused on improving the performance i.e-for performance metric such as throughput, of TCP when running over these IP-based networks. Despite the tremendous attention that has been given to improve TCP performance over wireless links, little consideration has been given to issues related to energy-efficiency of transport protocols such as TCP and User Datagram Protocol (UDP). Energy consumption associated with the execution of transport protocols at end systems i.e-hosts has become one of the important key performance issues that must be taken into consideration particularly for limited power mobile devices that have become so ubiquitous today.

The energy saving techniques from TCP/IP model demonstrate (a) that the congestion control implemented by TCP helps in saving energy by simply avoiding transmissions when the channel conditions are poor; (b) the throughput and energy efficiency may be significantly improved by selecting the right choice of parameters for the TCP version used; (c) The use of TCP segment caching as a technique to minimize energy consumption caused by expensive retransmissions. The main benefit of such an approach is that it does not require any changes to be made to the TCP protocol. However, it is hard to actually deploy this approach in portable devices because these devices are highly resource-constrained for resources such as memory and processing power.

One of the early protocols developed to improve TCP performance when packet loss occurs is the Partial Reliability Transport Protocol (PRTP). Unlike TCP which recovers from all lost/dropped packets, PRTP allows a certain controlled amount of packet loss which helps to improve energy efficiency and throughput as well as minimize delays. An energy-efficient version of TCP (E2TCP) was enhanced with PRTP and the impact of partial reliability on energy efficiency was demonstrated using simulations. E2TCP is used only on the last hop the wireless link between the base station and the mobile host for a wired/wireless connection and uses a combination of selective acknowledgments and a novel window management strategy aimed at reducing the time overhead. It is worthwhile pointing out that the use of partial reliability is effective only for those applications that can tolerate a certain amount of packet loss, such as multimedia applications. In, an energy-efficient TCP quick timeout technique was proposed for wireless local area networks that can improve energy efficiency by about five times over an unmodified TCP. The basic idea of this technique is for the MAC layer to provide feedback status of transmitted packets to the TCP layer, and for those packets dropped a quick timeout is triggered by the TCP layer. The net effect of this approach is to reduce the idle energy consumption. Other techniques for more specialized networks also have been proposed to improve the energy-efficiency of communication protocols.

2.4 Energy-Efficient Fixed and Cellular Networks

The highly exponential growth of mobile computing applications along with increasing mobility of users carrying all kinds of portable devices will continue to accelerate the demand for mobile wireless networks in the future. Mobile users will continue to expect high bandwidth and low delays from these mobile networks. All these user expectations and mobile infrastructures will lead to an increase in the energy consumption leading to higher emissions of CO2.

Traditionally, network discovery techniques assumed all network interfaces on a mobile device are active all the time and these interfaces continuously scan for signals coming from one or more nearby wireless access points. The disadvantage of this approach is that it quickly drains the battery power of the mobile device. Past studies have demonstrated that the power consumption of network interfaces dominate the total system power consumption for mobile devices. One approach that can be used to save energy is to activate the network interfaces periodically instead of keeping them "alive" all the time. The power saved with such an approach is inversely proportional to the frequency of activations of the interfaces.

Handoff is the process during which a mobile device keeps its connection active as it migrates from the coverage area of one network to another. With the emergence of different types of wired/wireless networks like wireless local area networks, Generalized Packet Radio Service (GPRS), Worldwide Interoperability for Microwave Access (WiMAX), etc., vertical handoffs are used to switch from one network type to a different one. The vertical handoff process is achieved by three basic steps: network discovery the process by which a mobile device discovers reachable wireless networks, handoff decision, and handoff execution. Today, with the availability of different types of networks, the network selection process as part of the handoff process has become more complex. This is because the choice of network to be selected needs to take into account several factors such as cost, Quality of Service (QoS) requirements of the user, QoS offered by the available networks, available services, and power consumption.

- *Improving hardware energy consumption of base stations*: one set of improvement techniques involve improving the hardware energy efficiency of the transceivers of the base station. The power amplifier is the component that uses the most power in the transmitter and its energy use depends on factors such as modulation used, the frequency band needed, and other operating conditions. To improve the energy efficiency of the power amplifier, different types of linearization methods, such as Cartesian feedback, digital pre-distortion and digital signal processing methods used in Wideband CDMA can be used.
- *Improving energy consumption used by system and software features of base stations*: one of the most common energy saving methods for base stations that has been used for quite some time by many mobile network operators is to turn off either some parts of the base station or the complete system when the traffic load for the base station site (cell) is low e.g., during night time. This approach is commonly used for small cells femto-cell and pico-cell that are typically deployed for indoor sites [12]. Some site-specific solutions have also been suggested and these include: (a) the deployment of indoor sites that use natural fresh air cooling instead of air conditioners, (b) having a base station design that brings the radio frequency transmitter closer to the antenna which will reduce energy losses by the feeder cable and improve performance in contrast to the traditional base station architecture where a coaxial cable runs between the in-building base station to the outdoor antenna.

4.5 Data Centers

Many dedicated facilities also known as data centers have been built recently to house large numbers of servers and storage systems. These data centers are being deployed to deliver different types of networked services offered by various businesses, governments, etc. Currently, the number of servers in data centers ranges from 10,000 to 100,000 with 150,000 servers emerging. Energy management is therefore becoming increasingly important to deal with the operational temperatures and increase the reliability of computing resources in data centers. Techniques that have been proposed to improve the energy efficiency of data centers have focused on three specific areas: (i) effective cooling methods such as the use of liquid cooling or fresh air cooling compared to the use of traditional air conditioning units, (ii) more energy-efficient servers through more efficient microprocessor and chip designs that use less energy and power management strategies, storage systems, and power supplies, (iii) the deployment of highly efficient load balancing approaches that can maximize the usage of server resources. Virtualization software using an encapsulating software layer also known as a Virtual Machine (VM)) that provides the same inputs, outputs, and behavior that would be expected from physical hardware is also being used as a promising technology that can maintain high utilization of servers.

III. Benefits Of Implementing An Energy Management System

The benefit of having energy efficient networking for the betterment of environment is the main reason of this paper, however for businesses and companies making profit and long-term growth is just as important. Hence, I have covered some of the advantages that would help a firm with the use of Energy management system. One of the durable areas to reduce facility costs, especially for bigger buildings like schools, hospitals, and factories—is energy management, especially without a designated energy management professional or energy management system. An energy management system (EMS) is a system of computer-aided tools used by operators of electric utility grids to monitor, control and optimize the performance of the generation and/or transmission system. Below I have put down 4 of the benefits of energy management system [7].

3.1 Reduce Costs

If anything, an EMS allows you to significantly reduce utility costs across the board, including heating, cooling, lighting, and water. An EMS tracks detailed usage over time and stores it within its centralized, digital repository, so you always have access to your building's historical energy data. This will allow you to budget better for energy usage based on time of year, weather, and so on.

3.2 Improve Staff Well-Being

When employees are in comfortable work environments, studies show that productivity and overall well-being is improved. Both consistent lighting and temperature control will create energy-efficient workplaces for all, increasing employee happiness and performance.

3.3 Improve Facility Performance

Not only does a highly functioning EMS improve employee performance, it vastly improves building performance, as well. By reducing energy waste and operating costs, you are naturally making more room in your budget for other areas of business, like marketing, promotions, salaries, and product spends.

3.4 Increase ROI

An EMS comes with built-in, cost-saving features, including emitting lower power during peak times, offering revenue-generating programs, and helping you identify energy leaks. With these features, it's nearly impossible not to see a return on investment on installing an EMS.

IV. The Future

Till now we have discussed the techniques which have been used currently and the ones we are using for efficient energy networking. Most energy-related networking research efforts undertaken then have been focusing on techniques that can extend the lifetime of the network including network nodes and battery-operated networked, mobile user devices and appliances. Surprisingly, this strong energy interest from the networking research community remained almost flat for almost a decade afterwards during which researchers continued to explore energy efficient mechanisms for wireless sensor networks and ad-hoc networks specifically most probably because of their ubiquity. Both academia and industry are now showing a renewed ever-increasing interest in energy consumption which is growing every year. There are many reasons for this sudden shift: the user base for personal computers and portable devices, and the number of different types of access networks, the use of IT equipment to meet the business computing needs all continue to grow at a rapid pace leading to an increase in the global energy consumption. The cost of energy also keeps increasing. Along with these two trends, environmental concerns caused by CO2 emissions have also begun to receive a lot of attention from hardware/software manufacturers, various regulatory commissions, governments, and energy policy makers of various countries around the world. These trends are expected to continue in coming years.

Many of the proposed energy-efficient optimization solutions for network adapters are limited in their flexibility and scalability. Future network adapters and switches need to provide programmable low-level functions, such as device driver and user functions that can enable further energy optimization techniques to be explored if required.

Next generation routers and switches continue to improve their performances. Faster processing speeds consume more energy. To cope with the corresponding increase in energy requirement by many silicon-based routers, recent trends have focused on reducing the packet processing depth, and highly integrated designs. Best energy efficiency is obtained with routers that use a minimum packet processing depth in a highly integrated design using denser and faster silicon for routing and switching. Custom made silicon designs operate with the best power efficiency over complex silicon design. However, one major shortcoming for specialized silicon is their inability to scale to support additional features in the future when new router functions become necessary.

Most of the related works on energy consumption for commodity protocol stack such as TCP/IP have focused mostly on improving its throughput with only a few of them which dealt with the protocol's energy-efficiency. These few efforts did not propose techniques that can optimize the energy efficiency of the TCP/IP stack. Instead, they focused on performance comparison studies of various flavors of TCP. The TCP/IP stack is used by every host connected to the Internet and there is significant room for improving the energy efficiency of this protocol stack when running over both wired and wireless networks. So far, work in this area has been slow and more efforts will be needed to improve the energy used by TCP-UDP/IP stacks in the future. Since evolution is part of networking now there has been rise and talks about Named Data Networking (NDN)which would in future replace TCP/IP protocol as it would be better in performance and also energy efficient. Right now, research is still going on NDN model and as to improving the protocol so that it can be used in all domains as a replacement for TCP/IP [8].

The number of mobile users worldwide is close to 5.3 billion with almost half a billion users accessing mobile Internet in 2009. This trend will continue and network designers and operators will need to support information access anywhere, anytime from any device as users roam around. Energy-efficient handoff has now become an important performance metric for network architectures supporting vertical handoffs among heterogeneous wired and wireless networks. While some cellular technologies e.g., Global System for Mobile Communications (GSM), have matured over the years with highly energy-efficient base station designs, energy-saving optimizations of base stations through small, compact designs and the use of optical technologies for various recent wireless technologies, Long Term Evolution (LTE), Wideband Code Division Multiple Access (W-CDMA) still remain to be explored in the future. Also, with the rise and demand for 5G [9] there is a room for lot of research to be done for implementing the best way to give end user faster bandwidth with low energy conservation.

Various types of high-performance equipment are being deployed in data centers. To support these high-performance requirements, data centers must provide more power for the equipment to perform efficiently and reliably. One of the strategies being investigated to improve energy use in data centers is the use of renewable energy sources to provide the required power need to operate the data center. Building data centers in those geographical areas with an abundance of renewable energy sources like solar, wind, etc. is one option that has been explored. Another option is to avoid multiple conversions between Alternating Current (AC) and Direct Current (DC). The basic idea in this case is to do the conversion only once at the data center rather than doing it several times at various servers as is done currently.

The use of more power is also causing more heat to be generated by data center infrastructures. To address the heat issue, many cooling strategies are being investigated and developed. To quantify the power efficiency of data centers, a metric such as the Power Usage Effectiveness (PUE) has been proposed. The PUE is defined as the total power used by the data center divided by the total power consumed by the ICT equipment. PUE can be used to benchmark how much energy is being usefully deployed versus how much is wasted on overheads.

Power and cooling efficiency improvements will continue to challenge the design of next generation, energy-efficient data centers. To achieve power efficiency, we need to develop solutions not only at the system level through well-known power management solutions but also through the careful integration of hardware solutions such as asymmetric multi-core microprocessor design, efficient packaging techniques, and energy-proportional hardware designs that focus on memory and disk subsystems which can reduce the power consumption of central processing units.

V. CONCLUSION

In conclusion we can say that at the earlier days when the rise in ICT had happened even though a lot of thought process was not given as to how the environment would be affected, but we have made the technology better with time and also focused on reducing the impact that it does to the environment.

Looking into the future, we can identify several fascinating trends. First, it is encouraging to note that increasing power efficiency or energy efficiency requirements do not hamper the development of a faster Internet. Which encourages more researches to develop better energy efficient techniques. Second, the need for power efficiency stimulates fresh thinking in the network data plane area. The progress of networking in the last 25 years has left a great deal of overhead in the form of features, protocols and capabilities that are rarely used and can be dropped as redundant or obsolete. This “de-featuring” trend, combined with topological simplification, could well signal a return to elegance and efficiency in the world of telecommunications.

In addition, we are still witnessing increasing energy costs year by year. To address these systemic challenges, we need to continue to develop innovative, cost-effective, and energy-efficient solutions that can minimize the energy consumption of ICT technologies and exploit renewable energy sources wherever possible. This can be achieved if power-awareness is fully taken into consideration in the design, implementation, deployment, and maintenance of ICT technologies. It is worth mentioning that various energy policies and standards will also continue to play a notable role in optimizing energy-efficiency of ICT equipment as well as their usage by the consumers.

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