A Review of Energy Efficiency in Telecommunication Networks

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***Abstract* — This paper presents the concept of green telecommunication networks providing information about the power consumption within fixed line and wireless communication networks. It outlines the significance of energy efficiency in modern and future telecommunication networks and suggests directions for optimizing network performance in terms of energy demands. Numerous examples and reviews are also discussed. The aim is to introduce the reader to current green technologies and outline the necessity for energy efficiency in information and communication technology.**

***Keywords* — Green telecommunication networks, ICT and energy efficiency.**

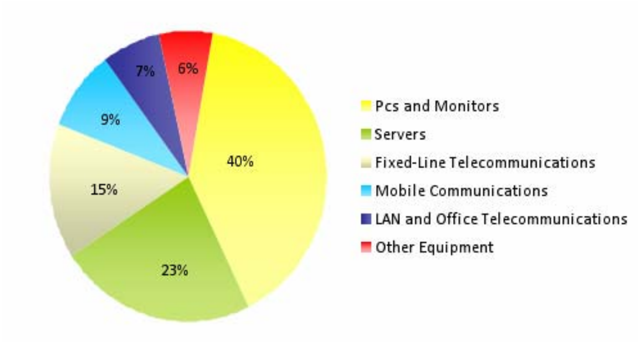

Fig. 1. Energy consumption in ICT sectors [1].

I. Introduction

It is a worldwide goal to reduce the energy consumption and the CO_2 emissions. European Union has targeted a reduction of 20% for year 2020. Part of this energy reduction scheme concerns the telecommunication industry and ICT in a direct, indirect and systematic approach [1]. Characteristic examples are green networks, smart buildings, smart grids, Intelligent Transportation Systems (ITS), energy efficient electronics (OLEDS, photonics, nanotechnology) and the application of embedded systems towards low carbon and energy efficient technologies [1-4].

Telecommunication networks constitute a major sector of ICT and they undergo a tremendous growth. Capacity issues and delivery of complex real time services are some of the main concerns of that growth and they rely on high power consumption schemes. In the increasingly competitive mobile telecommunication sector operators are turning to emerging markets for their next step growth situation that increases the number of subscribers and required base station equipment. This creates the need for equipment installation to areas where off grid renewable energy solutions are required and energy efficient networks are important [5]. In addition, the increase of fuel and electricity costs bounds the OPEX of the system.

Telecommunication networks and broadband access is proved to consume huge amount of energy for data delivery. In general, the telecommunication sector counts for the 2-4% of global electricity consumption [6]. Observations and discussions on the importance of energy efficiency in the telecommunication industry are reported by ITU in [1]. According to [1, 4] an important reduction of CO_2 emissions can be accomplished by focusing in innovative telecommunication services like online taxation, video conference, online billing that can enable a green economy. The goal is to drive the deployment of networks to power efficiency, yielding to a small ratio of required Watts per Gbps. Green initiatives have already been commenced by different operators. This paper discusses and proposes various energy efficient techniques to transform the operation of telecommunication networks to a green manner. The paper briefly discusses the fixed line networks and focuses on cellular networks that suffer most of the power waste nowadays.

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II. Power Consumption in Telecommunication Networks

ICT incorporates various electronic equipments and technologies that are widely used in modern societies. Fig. 1 presents the power consumption of the different sectors of ICT and it is observed that almost 50% (including the operation of servers) is due to the operation of telecommunication networks. These can be mobile networks, LANs and fixed line networks.

Fixed line networks and mobile networks present crucial differences as far as the power consumption is concerned [1]. For the first case more than 70% of the overall power consumption occurs in the user segment (power is distributed) and only the 30% is due the operator OPEX. On the other hand for mobile networks, a portion of 10% of the overall power consumption corresponds to the cellular user whereas 90% is by the operator OPEX. Neglecting the core network operation, fixed line networks suffer great losses due to cable transmissions, routing and broadband access whereas mobile networks consume huge amount of energy for base station operation. Fig. 2 presents how the power consumption is distributed across the different functionalities of the network. As far as the overall network performance is concerned the energy consumption is higher at the access part of the network and the operation of the data centers for management of the information. On the other hand, backbone and aggregation network present less energy demands [6]. This makes clear that an energy efficient architecture should focus on intelligent and efficient access techniques and efficient operation and data manipulation by the data centers. The main functionalities of a network can be summarized as the process of regeneration, transportation, storage, routing, switching and processing of data [7]. In Fig. 2 the corresponding portions of power consumption of these processes are presented and it can be observed that the majority of the energy is consumed for routing/switching, regeneration and processing of data. Both communication protocols and electronic devices are responsible for this consumption and this imposes challenges for more sophisticated transport techniques, thermal removal from the switches or the servers and less redundant data transfers. A characteristic example of energy efficiency in electronic equipments for these functionalities is shown in Table 1.

TABLE 1: POWER EFFICIENCY OF TELECOMMUNICATION EQUIPMENTS [7]

Equipment	***Power Efficiency (W/Gbps)***
Router	40
IP Switch	25
Transport TDM	80
ATM Switch	80

For mobile networks, a crucial factor affecting the network power consumption is the site operation that incorporates base station equipments [5, 8]. In the last part of Fig. 2 the power within the overall site and the base station (BTS base transceiver station) itself is presented. It is obvious that the most energy is consumed for cooling of equipments and base station operation. Monitor operation and lighting requires the minimum of energy whereas for the backhaul energy consumption the picture is not clear and depends on type of connections of the backhaul network (fiber or cable). Within the base stations high power demands are due to the feeders (transmission of radio waves), the RF conversion units and power amplifiers, the signal processing units and various electronic equipments such as climate and auxiliary equipments. In the following part of the paper, some already 'running' research activities in this area are investigated and different directions for optimising network's energy performance are proposed.

III. ENERGY EFFICIENCY IN TELECOMMUNICATION NETWORKS

Making a network to operate in a green manner is a complex task. Sometimes, optimizing energy consumption in one part of the network can increase power

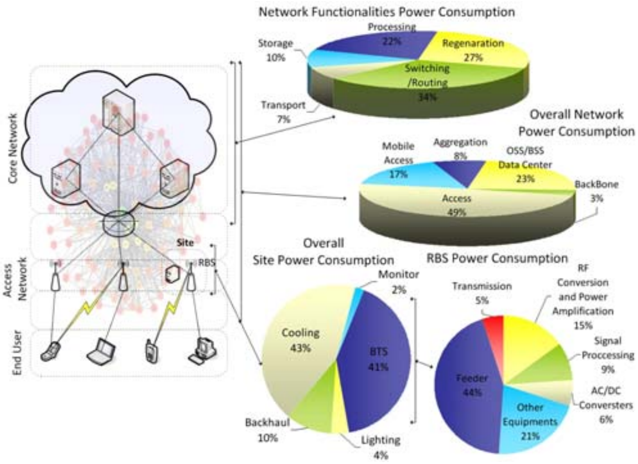

Fig. 2. Power consumption in different layers of the network.

consumption and degrade the performance to another part of the network. In general, total network optimization is better than the sum of optimization of individual parts. A network to work in an energy efficient way is not only a matter of environmental protection but also a crucial factor for the deployment of future networks to off grid areas that rely on Renewable Energy Sources (RES) or personal and sensor networks that rely on battery power supply. Minimizing power consumption has also a great affect at the cost of operation of a network and this makes it more affordable to the user. Network energy efficiency can be considered as a very complex task since there is no clear solution to the problem. There is always a trade off between quality of service, coverage, capacity issues and power consumption. In section II of the paper, the power consumption within a network was investigated. The observations can drive to the conclusion that optimization of the network in terms of energy efficiency can be achieved by providing the following key steps named as efficiency to network dimensioning, efficiency in the network processes, efficiency to the access network, efficient electronic equipments, use of RES and remote monitoring of the network for better management of the equipments (Fig. 3).

Optimization of user equipments is the first step for an energy efficient network. This requires low power electronics like OLEDs displays, efficient battery technology and not 'always on' attitude by the user or the network. In addition, recycling of equipments and eco friendly packaging are considered valuable solutions for energy efficiency since consumption of electronic equipments and gadgets has dramatically increased.

A. Fixed Line Networks

The key points for energy efficient fixed line or broadband networks are the green operation of data centers, the delivery of data to the end user via a low loss medium and the implemented power management schemes (Fig. 4).

Data centers and servers constitute important elements of the networks providing data processing, storage, regeneration, etc. A metric for energy efficiency of data center is the Data Center Infrastructure Efficiency

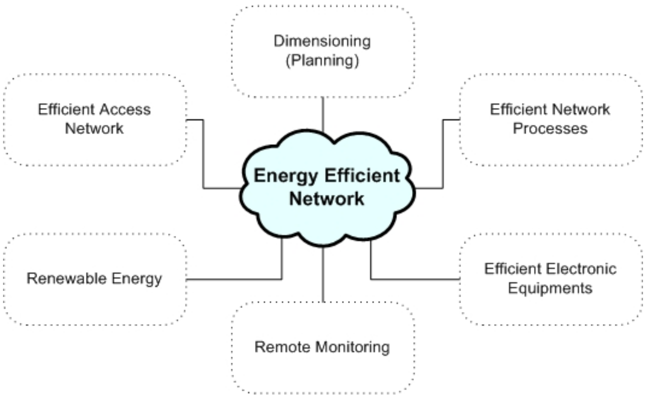

Fig. 3. Main factors for energy efficient network.

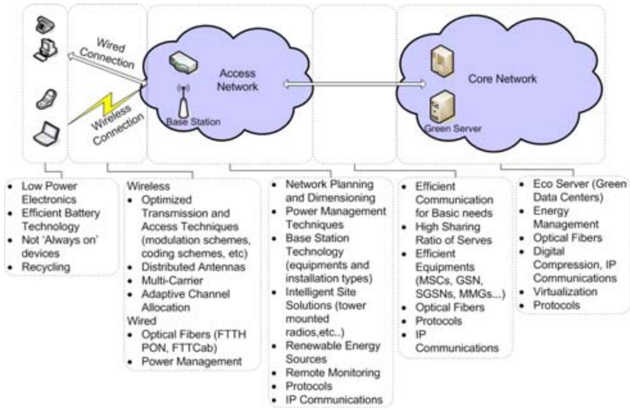

Fig. 4. Energy efficient solutions of telecommunication

(DCIE) [9] that expresses the fraction of the total power supplied to the data center and is delivered to the IT load. The losses are due cooling processes of the electronic equipments, oversizing of non critical components and the inefficient data manipulation and workload management. The importance of energy efficiency within the data center can be justified if one considers that a watt saved in data center power consumption saves at least a watt in cooling. Furthermore, power management of data centers can be considered as an important element for the efficient operation. It is observed that in a typical data center, the electricity usage hardly varies at all, but the IT load varies by a factor of three or more proving poor power management techniques. Finally, the use of multicore chip designs within the processors of the data center showed a marked decrease in overall power consumption [9].

Fixed line networks suffer great losses due to data transfer from the network to the end user. Optical fibers are considered as the best fitted solution for energy saving, providing at the same time high data rates. An investigation of optical versus electronic networks shows a superiority of fibers in terms of power consumption [6]. It is found that a Fiber To The Home (FTTH PONS) access dramatically reduces the required energy due to sharing. In addition, light propagation suffers fewer losses compared to electrical signals and this minimizes the required amplification and signal processing units within the network.

Another important factor that affects energy efficiency of the network is the 'always on' attitude of the user. In broadband access it is observed that over a ADSL connection, the power consumed by the DSLAM is not highly correlated to the traffic variations observed during the day. This situation proves that keeping always on connection without the need of data transfer reduces the power efficiency of the network. A power management scheme is proposed for the optimum performance of fixed broadband networks. Comparisons of power managed DSL and no power managed DSL connections shows a 50% reduction in power consumption [6]. A three state scheme is believed to best fit the needs for this approach that incorporates full on, low power and idle state.

B. Mobile Networks

Mobile networks provide national coverage that requires huge amount of energy to operate. In addition, they can sometimes be deployed in areas where there is no grid power available [5] and operation is limited by the available power from RES or batteries. Furthermore, the connectivity with mobile users and terminals operating under batteries necessitates for an efficient communication between the base stations and the terminals in terms of data delivery and power consumption. The dominating energy consumption part of a mobile network is the base stations providing wireless transmission of data (Fig. 2). The green operation of mobile networks mainly depends on base station infrastructure/design and the efficiency of the electronic equipments, the optimized network planning, the efficient transmission techniques and physical layer characteristics (access schemes, modulation , coding, etc) and the penetration of RES within the network (Fig. 4).

For cellular networks, an intelligent and efficient network planning is of most importance. The deployment of a cellular system under strict and efficient plans can dramatically reduce the required number of base stations to cover a given area. Of course, this has great affect to the power consumption of the network and the quality of service since interference and synchronization processes are minimized. In addition, if one considers the energy waste and CO_2 emissions for site visits the importance of site minimization becomes stronger. In [8] it is shown that an optimized plan can reduce the number of required serving stations by 40%. The optimization in terms of RF planning incorporates accurate propagation models and sophisticated optimization techniques.

The physical layer of wireless communications (modulation, coding, channel access schemes, etc) is more power demanding compared to fixed access due to serious signal impairments of mobile radio channels. The communication between the serving station and the mobile user requires overheads in data transfer that degrades the ratio of required Watt/Gbps. In [10] the impact of the physical layer to energy consumption of wireless networks is investigated. A similar study is shown in [11] where different access techniques are examined for High Altitude Platforms (HAPs) systems. HAPs suffer crucial power limitations since they are autonomous operating by solar energy. In both papers it is found that the characteristics of the physical layer hold an important factor to energy consumption of the network and they depend on the traffic load and the environment of each scenario that need to be considered in the deployment of the system.

The access network of cellular systems requires a dense deployment of sites and base stations to provide a reliable communication link between the user and the network. Renewable energy supply (like solar and wind) is considered as the first option for energy efficiency of the sites. The problem is that the deployment of these depends on local meteorological conditions which are not always ideal for every location [5, 12]. The main viability factors for green power deployments of mobile networks sites are the regional cost of distributed diesel, the solar and wind conditions and the load requirements of the site. For that reason a combination of diesel generators with RES energy supply and battery banks is proved as the optimum solution [8]. In parallel, power adaptation and management techniques are required to increase the efficiency of base station operation. As an example, intelligent power management can monitor the traffic and power consumption of different components of the base station, identify idle components and can decrease carriers and time slots (channels) to provide energy efficiency. Power management and power reuse solutions are investigated in [4, 13, 14]. Furthermore, the deployment of CDMA 3G systems that utilize power control and soft handoff resulted to more efficient utilization of the available resources. Power management in wireless cellular networks is also achieved by adaptive channel allocation. During low traffic demands, channel management reduces the amount of energy transmitted by the base station [15, 16].

As far as the base station operation is concerned the most energy is wasted for cooling purposes due to electronic equipment inefficiencies. It is shown that the incorporation of advanced power amplifiers can minimize the power demands. As an example, the adoption of DPD (Digital Pre-Distortion) coupled with Doherty technology improves the power amplifier efficiency to over 30% from about 9% without DPD and Doherty. In addition, envelope tracking for more efficient amplification of the signal proved to reduce power consumption by these equipments in a critical manner [17, 18]. Furthermore, multicarrier technology may provide power efficiency by decreasing the required power per user. Distributed base stations systems may share the baseband units by different radio remote units or tower mounted antennas minimizing cooling equipment and transmission losses though cables. Intelligent site location can also result to a decrease of the power consumption since the location and the number of the required BTS is highly correlated to the energy consumption of the network.

Thermal removal and cooling of electronic equipments are power demanding processes that degrade the performance of the system. One option is to investigate different thermal removals techniques like fresh air flow within the base station and another approach to this problem is to increase the electronic equipment's tolerance for higher temperatures. A study proved that by increasing the tolerance from 21^{o}C to 25^{o}C of a power amplifier a reduction of the overall base station of 10% can be achieved [19].

At the core network part, power management can be obtained by advanced communication protocols. In future communication networks, protocols should be designed in order to establish a reliable connection but at the same time be power efficient. In addition a high sharing ratio of the servers is required for less consumption. Finally, mobile IPv6 scheme performs a power saving option for cellular and WLAN systems [20].

IV. Conclusions

The concept of green telecommunication networks was investigated. Fixed line and cellular networks are driving their technology to energy efficient directions. Fiber optics and power management of fixed broadband networks proved to be a solution whereas for mobile operators, access networks and base station technology is of most importance. The sectors of the network that require the most attention are the electronic equipments of both end user and the access network, thermal removal processes, efficient network planning and the base station design.

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