A Review of Energy Efficiency in Telecommunication Networks

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Abstract **— This paper presents the concept of green telecommunication networks and provides 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.**

I. Introduction

IT is a worldwide goal to reduce energy consumption and CO_2 emissions. The European Union has targeted a reduction of 20% for year 2020. A part of this energy reduction scheme concerns the telecommunication industry and ICT that participates in a direct, indirect and systematic way [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 that yield high power consumption patterns. 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 are proved to consume a huge amount of energy for data delivery. In general, the telecommunication sector accounts for approximately 4% of the 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 on innovative telecommunication services like online taxation, video conference, online billing that can enable a green economy. The goal is to deploy telecommunication networks enabling power efficiency, yielding a small ratio of required Watts per Gbps and Watts per user. Green initiatives have already been commenced by different operators. This paper discusses and proposes various energy efficient techniques for the green operation of telecommunication networks. The paper discusses fixed line networks and cellular networks that suffer most of the power waste nowadays.

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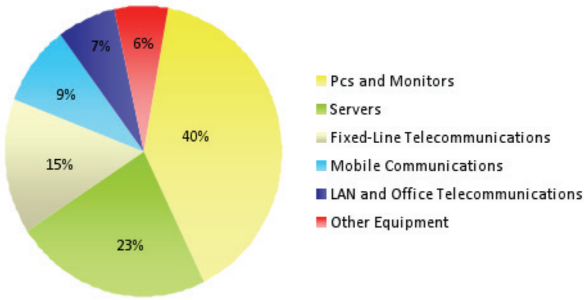

Fig. 1. Energy consumption in ICT sectors [1].

II. Power Consumption in Telecommunication Networks

Fig. 1 presents the power consumption of the different sectors of ICT. It is observed that almost 50% (including the operation of servers) is due to the operation of telecommunication networks. These can be mobile networks, WLANs, LANs and fixed line networks.

Fixed line networks and mobile networks present a different power consumption pattern [1]. Concerning the fixed line networks, more than 70% of the overall power consumption occurs in the user segment (power is distributed) and only 30% is due to 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 incurred by the operator OPEX. Neglecting the core network operation, fixed line networks suffer great losses due to cable transmissions, switching/routing, broadband access and data centers whereas mobile networks consume a huge amount of energy for base station operation. Fig. 2 presents how the

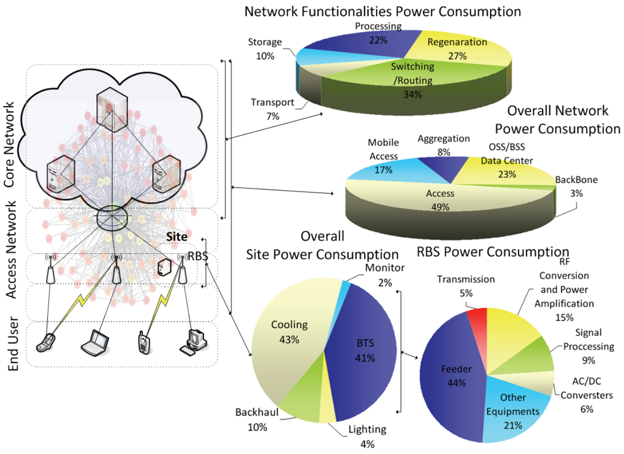

Fig. 2. Power consumption in different layers of the network.

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 data centers that provides computations, storage, applications and data transfer in a network. On the other hand, backbone and aggregation networks present lower 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 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 power consumption patterns of these processes are presented and it can be observed that the largest part of 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 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 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 greatest portion of 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 the type of connections of the backhaul network (fiber or cable). Within the base stations, high power demands are due to feeders (transmission of radio waves), the RF conversion units and power amplifiers, signal processing units and various electronic equipments such as air conditioners and auxiliary equipments.

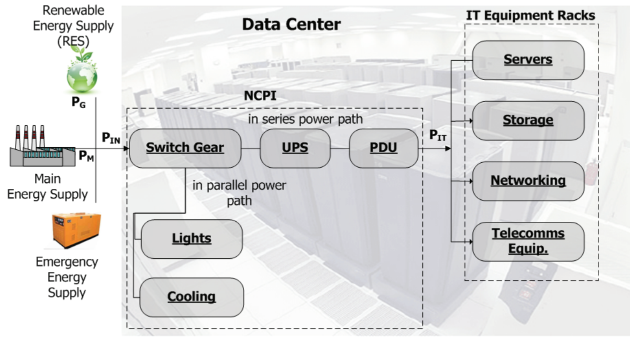

Fig. 3. Structure of a typical Data Center.

A. Data Centers

The overall power consumption of a data center is related to the associated power consumed by each unit. Efficiency at individual parts is an important step for 'greening' the data center but optimization is achieved when the efficiency aims to the overall data center design. The power distribution in a typical data center is presented in Fig. 3 [9], [10], [11]. The input power is divided into an in-series path and an in-parallel path to feed the switchgear and the cooling systems, respectively. At the switchgear, UPS and PDUs great losses occur due to AC/DC/AC conversions in the form of thermal heat. Typical UPSs present an efficiency of 80%. The parallel path feeds the cooling system that is important for heat protection of a data center. The cooling system incorporates fans and liquid chillers. The power consumption at different layers of the data center is presented in Table 2. It can be observed that the useful work of data center is associated to a percentage of power, smaller than the 30% delivered to the IT equipments.

The power consumption pattern is not constant in time but varies depending on different parameters. The main are the input workload to the data center and the surrounding environmental characteristics. The IT equipments present non-constant losses and variable energy efficiency that depends on the input workload. Power waste is mainly due to power units (UPS, Transformers, etc…) that operate below their full load capacities, UPSs that are oversized for the actual load requirements in order to avoid operating near their capacity limit, air conditioning equipment consumes extra power in order to deliver cool air flow at long distances, blockages between air conditioners and equipments, no virtualization and consolidation, no energy management and monitoring, use of non energy proportional computing servers and, finally, to oversizing of data center.

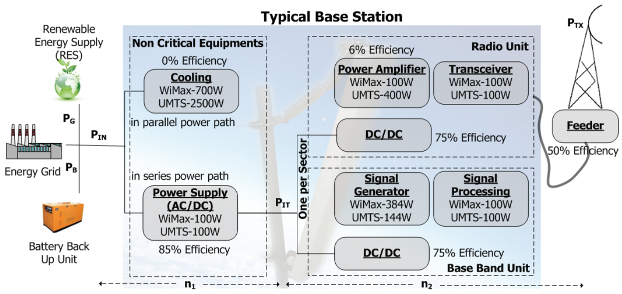

Fig. 4. Structure of a typical cellular base station.

TABLE 2: POWER WASTE DISTRIBUTION IN TYPICAL DATA CENTERS

NCPI equipments	***Percentage of Power Consumption[Total 70%]***
Chiller	33
CRAC	9
UPS	19
PDU	5
Switchgear, Lights	4
IT equipments	***Percentage of Power Consumption relative to [Total 30%]***
System	25
Disks	5
Power Supply	13
Networking	9
CPU	40
Memory	8

B. Cellular Base Stations

Base stations are the most energy demanding element of cellular networks. The block diagram of a typical base station accompanied by typical consumption patterns for WiMax and UMTS networks is presented in Fig. 4 [12]. The power consumption within a base station exhibits important similarities with data centers. The available power from the electricity grid, the battery back up unit or the renewable energy (RES) enters the base station and is divided into an in-series path and an in-parallel path. Non- critical equipments support the operation of the IT equipments that are divided into radio units and baseband units. The power consumption pattern is also presented in Fig. 2. The most energy consuming devices of base stations are the cooling infrastructure, power amplifiers, RF feeders and the AC/DC and DC/DC conversion units. Depending on the number of sectors, n_{SC}, and the antenna number, n_{TX}, of the base station, the total power consumption is computed as follows

$$P_{IN} = n_{SC}[n_{TX}P_{AMP} + P_{TRANS} + P_{PROC} + P_{DC/DC} + P_{GEN}] + P_{COOL} \quad (1)$$

In the above formula an additional factor models the power consumption due to RF links of the base station. For macrocell and microcell base stations, empirical formulae can describe the relationship between the power delivered to the antenna relative to the consumed power of the base station [13]. For macrocell stations the power consumption is almost independent of the input load (traffic) whereas for microcells, power consumption is highly dependent on the input load. The relationship is

$$\begin{aligned} P_{MACRO} &= a_M \cdot P_{TX} + b_M \\ P_{MICRO} &= L \cdot (a_N \cdot P_{TX} + b_N) \end{aligned} \quad (2)$$

In the above formula and for typical LTE stations a_M=21, a_N=7.84 and represent the power consumption due to power amplifiers, feeders and cooling and b_M=344 Watts, b_N=71.5 Watts represent the power consumption due to signal processing, battery back up, site cooling and in general processes independent of the radiated power of the station. Parameter L represents the load of the station and satisfies $0<L<1$. Equation 2 represents the average power consumption and depends also on the number of sectors per site and the number of microcell stations per site. The efficiency metrics n_1 and n_2 correlate P_{IT} with P_{IN} and P_{TX} with P_{IT} respectively (Fig. 4).

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 consumption and degrade the performance of another part of the network. In general, total network optimization is better than the sum of optimizations 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 effect on 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 the 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 lead to the conclusion that network optimization in terms of energy efficiency can be achieved by providing the following key steps named as efficiency to network dimensioning, efficiency in network processes, efficiency at the access network, efficient electronic equipments, use of RES and remote monitoring of the network for better management of the equipments (Fig. 5).

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 and low carbon economy 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

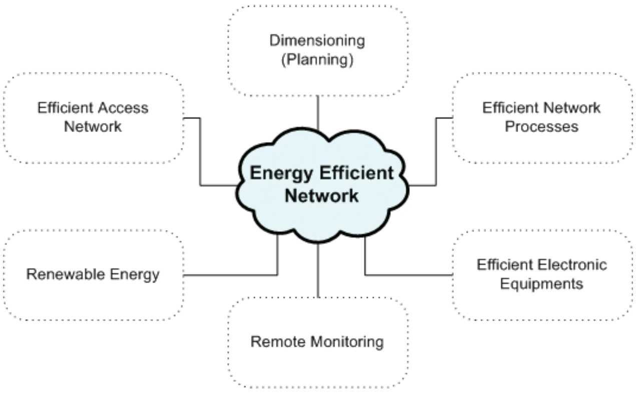

Fig. 5. Main factors of energy efficient networks.

medium and the implemented power management schemes (Fig. 5).

Data centers and servers constitute important elements of networks providing data processing, storage, regeneration, etc. A metric for energy efficiency of data center is the Data Center Infrastructure Efficiency (DCIE) and the Data Center energy Productivity (DCeP) [14]. DCIE expresses the fraction of the total power supplied to the data center and is delivered to the IT load whereas DCeP correlates the data center throughput with the consumed power. In a mathematical form they are expressed as

$$DCIE = \frac{P_{IT}}{P_{IN}}, \quad 0 < DCIE < 1$$
$$DCeP = \frac{Useful\ \ Work}{P_{IN}} = \frac{\sum_{i=1}^{m}\left[V_i \cdot U_i(t,T) \cdot T_i\right]}{E_{DC}} \qquad (3)$$

The term "useful work" describes the number of tasks executed by the data center and P_{IN} or E_{DC} represents the consumed power or energy, respectively, for the completion of the tasks. In the above formula m is the number of tasks initiated during the assessment window, V_i is a normalization factor that allows the tasks to be summed, U_i is a time based utility function for each task, t is the elapsed time from initiation to completion of the task, T is the absolute time of completion of the task, T_i=1 when task is completed during the assessment window or 0 otherwise. The assessment window must be defined in such a way as to allow the capture of data center's variation over time. The DCeP factor gives an estimate of the performance of the data center and is not as accurate as DCiE due to its relativity. Proxies for computing the useful work according to the scenario of interest are presented in [15]. The losses are due to cooling processes of the electronic equipments, oversizing of non-critical components and the inefficient data manipulation and workload management.

An energy efficient data center requires operational and planning actions. Operational actions correspond to the IT and NCPI equipments and incorporate the use of energy proportional servers, the retirement of old processors and servers, the migration to more energy efficient platforms, such as blade servers, and the use of free cooling techniques and efficient chillers. Planning actions incorporate the exploitation of virtualization, remote monitoring and management of the data center, rightsizing

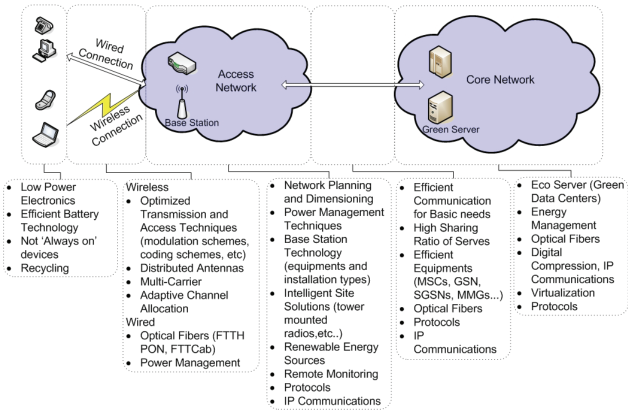

Fig. 6. Energy efficient solutions of telecommunication networks.

procedures and actions to reduce cooling needs through optimal design of the floor plan and proper arrangement of the equipments. The importance of energy efficiency within the data center can be justified if one considers that a watt saved in the 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 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 [14].

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 the 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 an 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. Cellular Networks

Mobile cellular networks provide national coverage and require a 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 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 station providing wireless transmission of data (Figs. 2, 4). The green operation of cellular networks mainly depends on base station infrastructure/design and the efficiency of the electronic equipments, optimized network planning, efficient transmission techniques and physical layer characteristics (access schemes, modulation, coding, etc) and the penetration of RES into the network (Fig. 6).

For cellular networks, intelligent and efficient network planning is of utmost 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. This can be achieved when a sophisticated radio propagation algorithm, a detailed GIS map coupled with an optimization technique is used [16]. In the literature it is shown that site minimization is important to reduce the CAPEX of the system but energy efficiency is achieved when the network is deployed with dense low power stations, optimally placed over the GIS map and taking into account CO_2 emissions for site visits and base station operation due to grid electricity [8], [13], [16]. In addition, dense low power base stations enable the penetration of RES into the network. 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 a 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 increases the ratio of required Watt/Gbps. In [17] the impact of the physical layer on energy consumption of wireless networks is investigated. A similar study is shown in [18] 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 are an important factor for energy consumption of the network and they depend on the traffic load and the environment of each scenario that needs to be considered in the deployment of the system. Adaptive modulation and coding techniques are important. A cross layer optimization technique that yields energy efficiency is also presented in [19].

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 RES depends on local meteorological conditions which are not always ideal for every location [5, 20]. The main viability factors for green power deployments of mobile network 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 (Fig. 4) [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], [21], [22], [23]. Furthermore, the deployment of CDMA 3G systems that utilize power control and soft handoff resulted in a 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 [21], [22], [24], [25].

As far as the base station operation is concerned, most of the energy is wasted for cooling purposes due to electronic equipment inefficiencies. It is shown that the incorporation of advanced power amplifiers can minimize 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 [26], [27]. 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 through cables. Intelligent site location can also result in a decrease of the power consumption since the location and the number of the required BTS is highly correlated with the energy consumption of the network [8].

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 removal techniques like fresh air flow within the base station and another approach is to increase the electronic equipment's tolerance to higher temperatures. A study proved that by increasing the tolerance of a power amplifier from 21°C to 25°C a reduction of the overall base station of 10% can be achieved [28].

At the core network part, power efficiency can be obtained by advanced communication protocols. A review of energy efficient communication protocols is presented in [29]. 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 servers is required for a smaller consumption. Finally, a mobile IPv6 scheme provides a power saving option for cellular and WLAN systems [30].

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, energy efficient data centers and power management of fixed broadband networks proved to be a solution, whereas for mobile operators, access networks and base station technology are of utmost importance. The sectors of the network that require the greatest attention are the electronic equipments of both end user and the access network, thermal removal processes, efficient network planning and base station design.

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