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Green Communications

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ABSTRACT: Green communication is an innovative research area to find radio communication and networking solutions that can significantly improve energy efficiency and resource efficiency of wireless communications without compromising the QoS of users. It contributes to global environment improvement and achieves commercial benefits for telecommunication operators. The main goal of designing green base stations is to save energy and reduce power consumption while guaranteeing user service and coverage and ensuring the base station's capability for evolution. In a wireless network base station, power consumption is the biggest issue. With global warming and energy crises becoming the most compelling environmental challenges, green solutions are a common issue to be handled. Hence, the primary focus of the “Green cellular network” is saving power in base stations to “care for planet and operator’s valet.” we reviewed a few techniques for saving power consumption and improving energy efficiency in base stations. However, many technical challenges for base station architecture redesign, heterogeneous network deployment, radio resource management, etc., need to be addressed for energy-efficient base stations.

KEYWORDS: Green, Green communication, Energy Efficiency, Cellular network

1. INTRODUCTION

With the explosive growth of mobile communications in terms of several connected devices and the demand for new services and ubiquitous connectivity, the energy consumption of wireless access networks is experiencing a significant increase. Global mobile data traffic grew by 63 percent in 2016 [1]. It stood at 7.2 billion Giga bytes monthly at the end of 2016. And by 2021, it will be 49 billion Giga bytes. In 2016, almost half a billion new mobile devices were added. According to Ericsson’s forecast, there will be 50 billion connected devices by 2020, as shown in Figure 1. This situation imposes a big challenge for mobile operators due to the high energy cost and increasing concern for global warming and sustainable development. Hence, it becomes urgent for mobile operators to support vastly different quality of service requirements of an increasing number of users in an energy-efficient manner. To support access to information anywhere and anytime at a low energy consumption would require a paradigm shift technology, such as energy-efficient network architectures, energy-efficient wireless transmission techniques, energy-efficient networks and protocols, smart grids, etc. Energy efficiency in MTs has been significantly improved, but the same work on BSs, which consume the most energy in mobile networks, has lagged. As a result, mobile operators are paying even more for the cost associated with the increased number of BSs. The fact that energy costs comprise a large proportion of total cost justifies ongoing efforts from telecommunication service providers to reduce energy consumption to improve their bottom coverage, capacity, and quality requirements. Figures show that their energy bills are now comparable to their personnel costs for network operations, which range from 18% (in the EU) to 32% (in India) of their total operating expenses (OPEX) [2] - [4]. In Germany, the electricity bill for mobile network operators is more than 200 million euros per year [5]. The global mobile network industry's revenues will shrink from 2018 onwards [6]. Apart from the direct economic benefits, environmental and marketing reasons (better corporate image can boost sales) are other driving forces for telecom providers to take the green initiative. Several telecom providers, such as PCCW and Vodafone, have reduced energy-related operating costs [7] - [9]. An analysis shows that total energy per unit traffic declined by approximately 20%, and energy per connection declined by 5% from 2009 to 2010, indicating that the industry is making significant efforts and some progress toward energy saving [10]. Notable collaborative projects that aim to reduce energy consumption in mobile networks include 3GPP [11], EARTH [12], OPERA-Net [13], C2POWER [14], eWIN [15], and TREND [16].

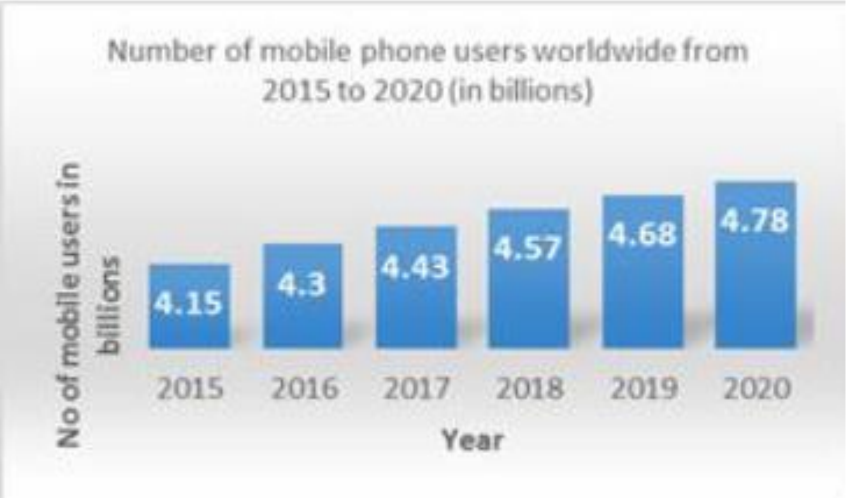


Figure 1. Estimate of mobile phone users worldwide [17].

At the outset of 5G, many cities will be deployed with small cells. The network's density will increase at a very fast pace. The Internet of Things (IoT) would need denser networks with lower latency and higher throughput.

for self-driving cars, buses, etc. New technologies like augmented reality and virtual reality are bound to demand higher data rates. These advancements will call for a strengthened mobile broadband network.

Recently, with the rising global temperature and climate change shown in Figure 2, saving energy has become very important. The rapid development of the Information and Communication Technology (ICT) industry has also increased power demand. ICT tends to play a significant role in global greenhouse gas emissions. It was responsible for 10% of the world’s total energy consumption in 2010, doubling every ten years [18]. Cellular networks are among the primary energy consumers in the ICT field. With an increased need for broadband speed, the demand for energy and the density of the networks is likely to increase. High energy efficiency is becoming a mainstream concern for the design of future wireless communication networks. According to [19], the number of CO_2 emissions associated with information and communication technology (ICT) was 151 Mt CO_2, shown in Figure 3. The wireless communication sector was responsible for 43% of this total, and this proportion is expected to increase to 51% of the total of 349 MtO_2 by 2020, given in Figure 4. The sector’s economics indicates that ICT currently consumes 600 TWh (Terawatt hours) of electrical energy and is expected to increase to 1,700 TWh by 2030. The cellular network represents the most significant component of the ICT sector.

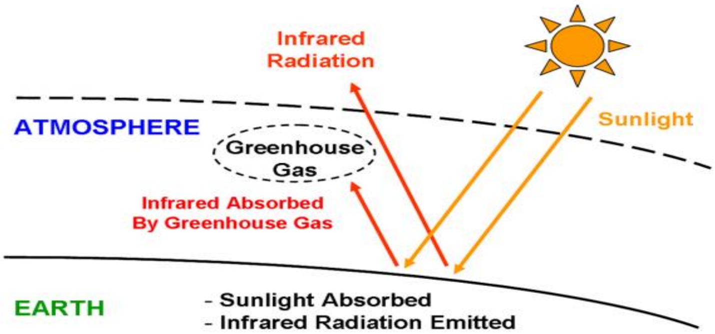


Figure 2. Greenhouse effect

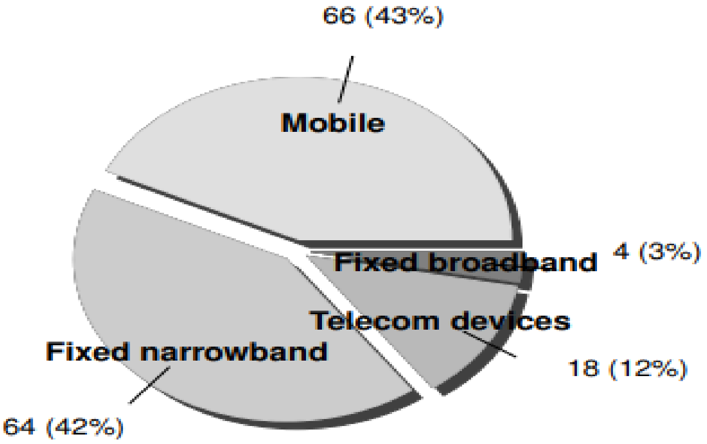


Figure 3. Global telecoms' footprint (in $MtCO_2$) in 2002 (100% = 151 $MtCO_2$).

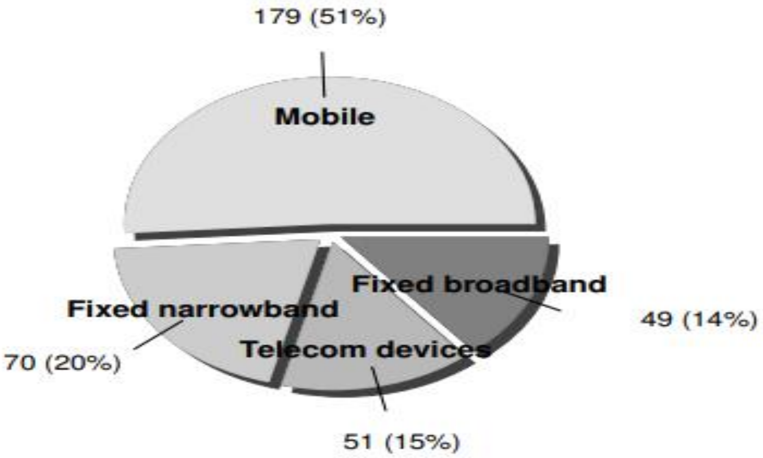


Figure 4. Global telecoms' footprint (in $MtCO_2$) in 2020 (100% = 349 $MtCO_2$).

With an increased need for broadband speed, the demand for energy and the density of the networks is likely to increase. High energy efficiency is becoming a mainstream concern for the design of future wireless communication networks. Green energy, also known as *clean* or *sustainable* energy, is typically produced from renewable energy sources, such as solar, wind, tidal, or geothermal, that cause minimal environmental impact and pollution. Green *communications* is a loosely defined marketing term in the telecommunications community. It can typically be thought to represent either the *greenness* of the telecommunication's Carbon dioxide (CO_2 -footprint, the act of attempting to lower the cost of the energy, or the attempt to lower the amount of consumed energy altogether without any perceivable impact on the QoS [18] – or it might even be used as an acronym for *Globally Resource-optimized and Energy-Efficient Networks* [20]. Green communications, in practice, could be generalized as different wireless networks whose coverage areas overlap each other and can cooperate to reduce their combined energy consumption by alternately switching their resources on and off according to the available network load conditions and demand. More specifically, green communication is an innovative research area to find radio communication and networking solutions that can significantly improve wireless communications' energy and resource efficiency without compromising users' Quality of Service (QoS). It contributes to global environment improvement and achieves commercial benefits for telecommunication operators. To cope with this issue, numerous remedies are currently under consideration [21- 23], such as:

- Improved power amplifier technology makes the hardware design of a typical BS more energy efficient.
- Employing power-saving protocols such as BS sleeping enables an inactive operation mode for BSs under low-load conditions.
- Cell size adjustment schemes such as cell breathing and zooming enable different cells to adapt their size depending on the received interference or traffic load conditions.
- Using renewable energy sources such as solar and wind energy instead of diesel generators may also help reduce the power consumption of BSs, particularly those at off-grid sites.

- Deployment of relays (e.g., amplify-and-forward) improves the power reduction with reduced complexity, albeit at an increased cost for infrastructure deployment.

2. RELATED WORK

The energy efficiency focus in green radios evolves from minimizing the energy consumption of the access point (APS) to producing the APs more economically with lower maintenance costs. This shift is due to the change in energy sources – from non-renewable (often plentiful and cheap) to renewable (albeit sometimes scarce) forms of power. Using renewable and sustainable energy sources (with the appropriate battery backups) can eliminate the issue of gathering and paying for energy. Green energy technologies are usually still more expensive to build than traditional ones, and so the center of attention moves from operational expenditure (OPEX) towards the capital expenditure (CAPEX) of the green BS systems, as noted in [24]. The article's authors also studied the wireless network resource deployment and management and ran simulations on different mechanisms to relay the network traffic. The article also demonstrated the importance of choosing the appropriate call admission control scheme for the network to preserve a desired QoS and performance.

One goal for attaining "green" can be to improve energy efficiency by reducing greenhouse gases. Still, on the other hand, the combined impact of these properties can take time to measure. The Green Grid Association of IT professionals published a one-time metric to assess wireless energy efficiency [25] and [26]. A metric called *Power Usage Effectiveness* (PUE), as shown in equation 1, was developed to measure the data center's total power consumption versus the power used by the servers, storage systems, and network equipment altogether:

$$PUE = \frac{Total\ facility\ power}{IT\ Equipment\ power} \qquad 1$$

A PUE ratio of equation 1 refers to the situation in which all of the power is used in the IT Equipment *(i.e., no air-conditioning or communication subsystems are required)*. This is often a somewhat unrealistic scenario. An alternative method presented in equation 2, especially suited for telecommunications systems to estimate the energy efficiency of the system, would be to divide the energy consumption of the communications system by the performance of the computational system:

$$Computational\ energy\ efficiency = \frac{Communications\ system\ energy}{Computational\ sydtem\ performance} \qquad 2$$

The numbers for the above equation can, however, be hard to come by, as it can be challenging to quantify the effectiveness of the communications system or even to decide which metric to use in the first place. BER is a standard link quality measure, whereas spectral efficiency (*typically in bit/s/Hz*) defines the information rate transmitted using a given bandwidth. A more reasonable and commercial point of view would be to divide the total consumed power by the total number of calls – or users, as shown in Equation 3

$$PUE = \frac{Total\ power}{Total\ number\ of\ calls} \qquad 3$$

Green radios are expected to operate from eco-friendly, constrained power sources like solar or wind power. Improving the energy efficiency at the protocol stack and in the system architecture, operational management, and physical layer elements is a constant challenge for researchers. The design of mobile networks has, until now, focused on reducing the energy consumption of terminals, whose battery power imposes stringent requirements on energy consumption. However, according to a recent survey, nearly 80% of the energy consumption of a typical cellular network comes from the BS side [9]and [27]. Furthermore, 70% of this consumption is due to Power Amplifier (PA) and air conditioning, which are used to keep the BS active even though there is no traffic in the cell (i.e., to guarantee coverage), as shown in Figure 5 making it a prime element that ought to be examined to enhance the energy efficiency in a BS. Also similarly, in the mobile terminal (MTs) (e.g., the cell phone), it is the wireless modem that accounts for the vast majority of the power consumed, even for high CPU-intensive tasks [28]. It is because of these mentioned high percentages that improvement of the energy efficiency in the PA is one of the key domains that need to be considered to enhance the energy efficiency in the BS equipment.

The PA's conversion from DC power to RF AC power to improve the input signal is lossy, and one of the critical properties that directly affect this efficiency is the input signal itself.

One of the fundamental input signal's characteristic properties is the modulation scheme. Non-constant magnitude modulation schemes (*e.g., OFDM, due to its high peak-to-average power -ratio (PAPR)*) have a strict linearity requirement, which usually requires a large back-off from the PA's saturation point. A large back-off, *or reserve*, is required, but the back-off also poses challenges for the PA as its efficiency is at its peak at the peak envelope power, and the efficiency tends to drop as its output power decreases.

A low PAPR enables the transmitter's PA to operate efficiently, whereas a high PAPR causes the PA to operate with a large back-off and low efficiency. Utilizing high-efficiency nonlinear switch-mode PA in various PA structures, or even DVS or envelope tracking, improves the PA's efficiency and linearity shown in Figure 6 approximates a typical PA response curve, in which the PA’s linearity curve begins to distort as the input power increases.

Having the PA operate in its linear response region typically helps to avoid signal distortion, which is also why the peak value is restrained from existing in this region.

Techniques exist for PAPR reduction, such as clipping, windowing, interleaving, elective mapping, and polar transmission, which can help increase the PA’s efficiency for OFDM signals [29]—Furthermore, multi-carrier BS technology, such as GSM.

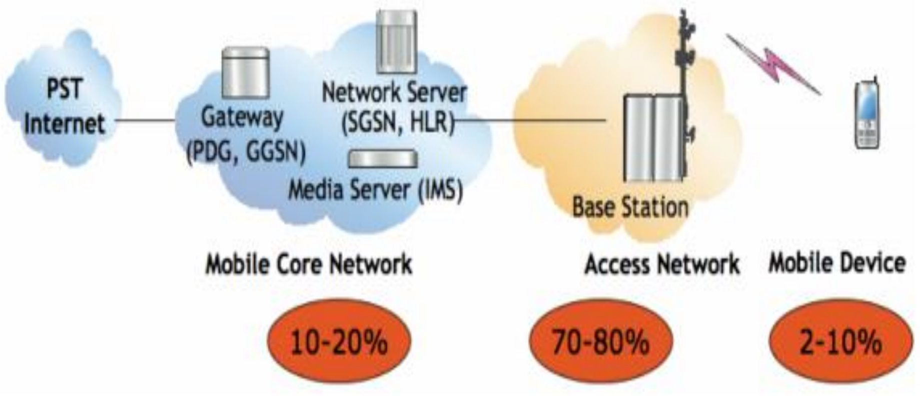


Figure 5. Impact on energy consumption of different stages of cellular network

Figure 5 shows the impact of each stage of the cellular network on global energy consumption. The main contribution is due to the radio access network because of the components of radio BS. In particular, BS power consumption can be subdivided into four main components: power amplifiers (65%), air conditioning and cooling (17.5%), signal processing (10%), and power supply (7.5%). Therefore, to make the cellular network greener, the starting point is to make the radio access stage more efficient, particularly the BS equipment. Radio access network consumes around 80% of the total energy in mobile networks and majorly in base stations which comes around to 60% of all [30]. Which stresses on call for reducing this energy consumption at the base station side.

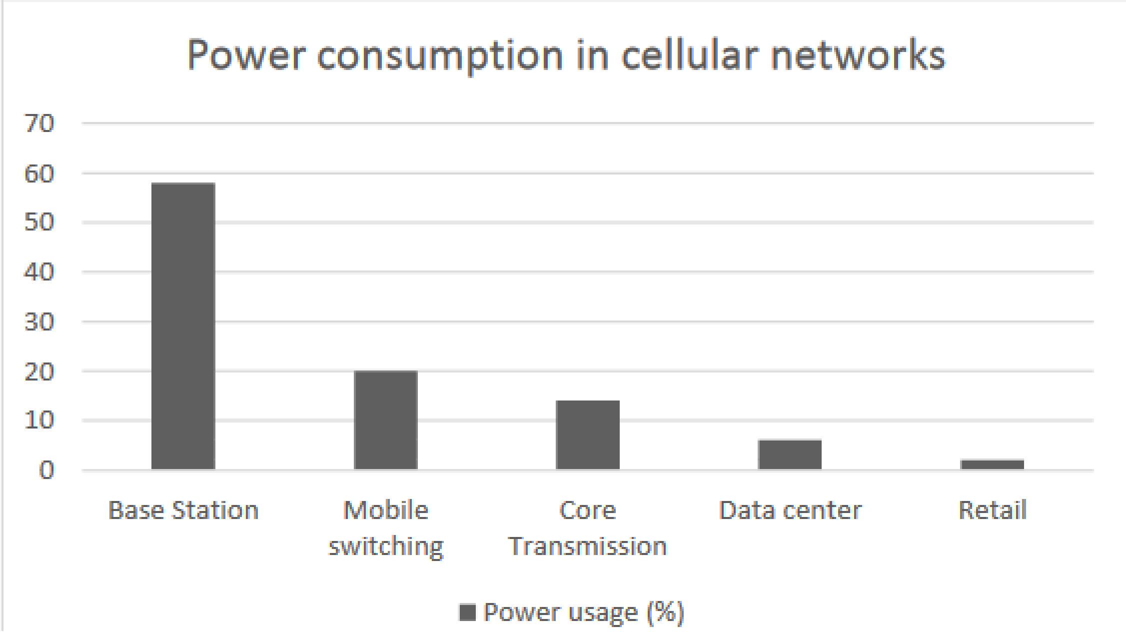


Figure 6. Breakdown of energy consumption in cellular networks [31]

Quadruple Transceiver Technology can reduce the maximum power consumption of the PA shown in Figure 7. Topology-focused network designs and improved network planning methodologies improve energy efficiency by reducing the number of required sites. The more minor and agile BS is ideal for a distributed BS architecture to replace the larger and more power-hungry macrocell BSs. In addition, game theoretic principles for lowering the OPEX have been used to analyze the energy efficiency in Code Division Multiple Access (CDMA) networks [32].

One key element for better energy efficiency in wireless communications is reducing the distance between the MTs and the BSs, as shown in Figure 8. According to [33], the joint deployment of macrocell BSs with publicly accessible residential picocells can help reduce energy consumption by up to 60%. Even though femtocells are paving a pathway to high capacity with low power, there remain some unresolved research issues concerning the distributed frequency management [34], [35], the interference avoidance between a femtocell and a macrocell [36], and handover, self-optimization, and pilot signal leakage [37]. Whereas the traditional radio design is designed to be used with a constantly available power supply, the green radios can successfully maintain their QoS with a randomly varying power supply.

When focusing on the energy efficiency of the BSs, the issue can be split into two categories: the network topology and the network elements -savings levels. The network topology-level energy-saving method means improving energy efficiency by reducing the number of BS sites. This leaves two options for implementation.

- Either increase the coverage efficiency of the BS and its processes through more efficient network planning and therefore need less energy per customer.

or

- Improve the BS coverage area to serve more users further away.

The network element-level savings are more easily approachable, as usually there are only a few elements to work with within a mobile site (typically only the BS, transceiver, and cooling equipment). Of these three, the BS is usually the most energy-hungry, making it the prime target on which to focus energy efficiency research.

Figure 9 illustrates a high-level concept map of the relations between energy efficiency and green communications in general. A green communications network consists of different electrical equipment: network peripherals, customer MTs, and cooling systems. By taking advantage of sophisticated communications technologies (*e.g., smart antenna, ultra-wideband (UWB) communications, adaptive modulation, coding schemes, and cooperative communications*), transmission energy efficiency can be substantially boosted. Software and applications in the form of intelligent energy management solutions can also complement the communication technologies to optimize further the system’s energy efficiency (*e.g., energy audit and* dynamic voltage scaling (*DVS) applications*). Network architecture, switching, and routing improvements can also amount to a significant wireless energy efficiency improvement due to the decreased network access time, accredited to the higher transmission rates, not forgetting the refinements in the resource allocation and net-work capacity planning. Hardware plays a key role in improving overall energy efficiency [24].

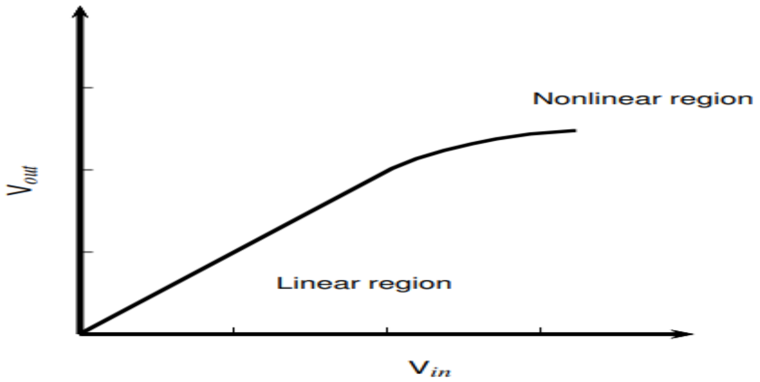


Figure 7. A typical PA response curve.

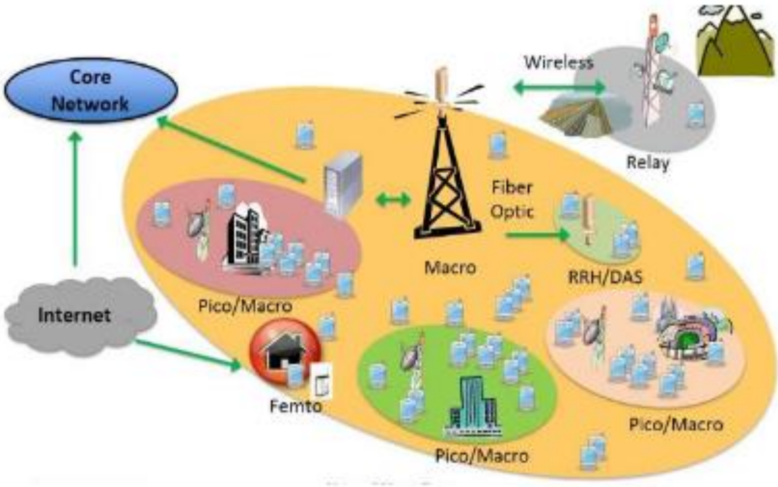


Figure 8. Heterogeneous network [38]

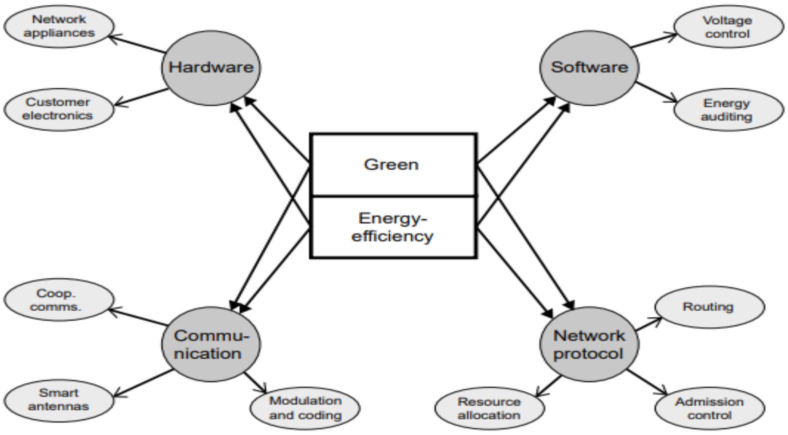


Figure 9. Associations between green and wireless energy efficiency.

The wireless networks in use today are typically dimensioned for performance optimization, with the so-called worst-case network planning philosophy in mind. The philosophy aims to maintain a specific guaranteed QoS at all times, no matter what the traffic in the network happens to be [36]. Reducing the time the BSs are unnecessarily powered on (*e.g., during a very low utilization period*) is another critical factor in energy savings. Having the unused BS site powered down when not in use saves energy and increases the site’s energy efficiency.

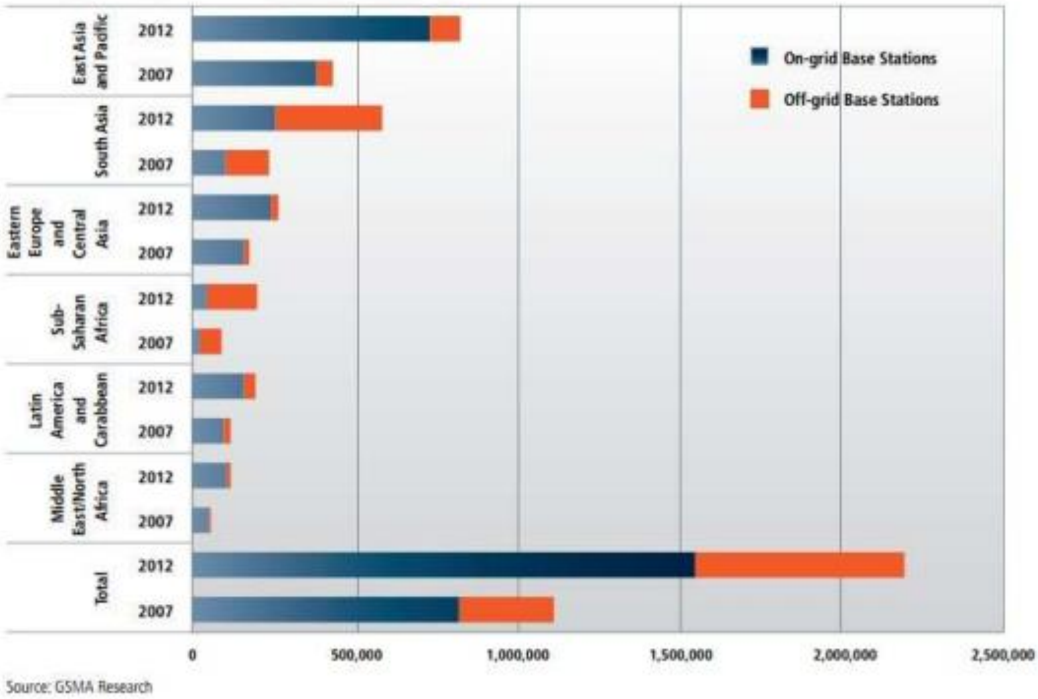
Arranging transmissions to MTs into fewer slots (albeit perhaps at the same time) to reduce receiving energy consumption, as well as an algorithm to find the optimal arrangement of such transmissions into each MT to reduce MT energy consumption, is presented in [39]. A resource on/off switching framework for adapting the energy savings to match the unstable wireless traffic load fluctuations while maintaining a preset service quality level was presented in [40]. While not overly significant, the feeder's losses still profoundly affect the BS's coverage capability. The loss of energy efficiency in the feeder is due to the reduction of the power fed from the PA into the antennas. This loss is manageable in MTs, as their feeders are quite short. Authors in [41] tackle the fundamental BS location problem and assignment of mobile users to appropriate BSs in a 3G W-CDMA uplink environment. The authors propose a constraint satisfaction model, applying variable ordering and value order techniques to find optimal solutions. Instead of cost minimization, the objective of their model is to minimize the total transmitted power. Once the location and power configuration of BSs are known, the next step is to study BS assignments at a higher level. This involves the investigation of an access network sub-problem. It is shown that local approaches aiming to reduce the energy consumption of individual network components can be quite practical. However, global approaches, considering the entire network's energy consumption in the network design, planning, and management phases, are a must for a holistic approach to energy-efficient networking. Compared to previous works on energy savings via BS switching, in [42] and [43,] the authors investigate the dominating factors in energy savings. Energy consumption of the BS amounts to nearly 850W, with the energy needed to transmit from the antennas amounting only up to 40W and the rest expended even in case of idle operation. Their analysis shows that the mean and variance of traffic profile and the BS density are the dominant factors that determine the amount of achievable energy saving. Moreover, an expression indicates that the energy saving increases when the traffic, mean/variance ratio, and the number of neighboring BS have a higher value. It means, for instance, that the most significant energy savings are likely to be realized in urban commercial areas (since such an area is likely to show high traffic and traffic variance between daytime and nighttime. It is also emphasized that the slope of traffic variation is more important than the maximum value in estimating the traffic profile because the slope determines the switching-on/off time.

In [44], the authors present a methodology to calculate energy savings by switching off BSs. The model energy consumption is a linear function of the number of BSs. Then, using the traffic profile for 24 hours, it is argued that as the traffic decreased by a factor X, a fraction X of the BSs can be shut down, and consequently, energy consumption will also be reduced by a factor X. Next, they remove the assumption that any BS can be shut down, and suggest that, in specific topologies, only certain BSs can be shut down to avoid coverage holes (e.g., in hexagon, six out of seven or three out of four BSs can be shut down). Similarly, the authors identify the number of BSs for crossroads (urban street scenario with each cell having four neighbors) and the Manhattan layout. Note that the paper assumes omnidirectional antennas are appointed in the center of the cells and does not quantify the loss of coverage or capacity or consider the local user demands when shutting down BSs. Authors in [45– 47] present a scheme for energy management of base stations according to the network traffic that incorporates binary on/off activation or continuous cell zooming capabilities at the BSs. It is shown that noticeable energy savings can be achieved for low network traffic. The author in [48] presents energy efficiency metrics and investigates the performance of different planning strategies for long-term evolution and alternative nomenclature 4G (LTE) networks in an empirical way. In [49], the authors propose incorporating the on/off switching of BSs in the planning process. They first present a heuristic to have a minimum number of BSs. A Verona tessellation is first established in this algorithm, and then BSs are classified into feasible and infeasible sets. A feasible set consists of BSs whose removal will not decrease the coverage below the threshold. This step is repeated until no BS can be removed without decreasing the coverage. To incorporate on/off switching, first, the network is planned for the lowest traffic (this defines the infeasible set that cannot be switched off), and then it is planned for the highest load. Turning on additional BS and finding their locations is done by repeating the same algorithm. In [50], the authors use a detailed energy consumption model of the BS and definitions of site load factors to predict how much energy will be consumed to provide target capacity demands (100 Mbps in the paper). They take the energy consumption and capacity of existing HSPA+ in Finland (2008) as a reference and compare it with that of LTE while considering the gains obtained in LTE by node level (energy/capacity) efficiency and network level deployment strategies. Traffic-aware network planning operation (TANGO) is a framework to increase energy efficiency while guaranteeing radio coverage and optimizing radio resources. TANGO focuses on switching from the always-on BS scheme to an always-available scheme, switching to dynamic cell planning from static planning, and switching from uniform services to differentiated ones. The basic idea is [20]. To only have enough BSs operating at any given time that is necessary for adequate service quality., To utilize cell zooming to influence the cell size according to the prevailing traffic conditions as well as to the situation of neighboring BSs., To delay traffic, if possible, to utilize network resources when they are the most abundant or refer to the traffic variation and the adaptation of the available wireless resources into it – a bit like a gentleman (traffic needs) and a lady (power and other radio resources) dancing together harmoniously. To be able to relentlessly match the wireless network's traffic variation and adapt the radio resources (including transmitting power and other equipment's power) in a cell or the whole cellular network gives possibilities for saving large amounts of energy, as well as for the efficient use of network's resources. In [51], a static BS sleep pattern is formulated using a deterministic traffic variation pattern over time. The article doesn't, however, consider the randomness or the spatial variation of traffic. In [52], a resource-on-demand strategy for high-density centralized WiFi networks was proposed. In the article's strategy, a cluster-head AP is responsible for taking care of the whole cluster coverage to switch off the other APs in the cluster as long as the traffic load in the network is low enough. The channel model of Wi-Fi is, however, rather different from that of a cellular network, in which the path loss is normally dominant, which is also why a dynamic clustering algorithm considering BS collaboration is needed. In [53] and [54], the authors discussed scenarios where wireless traffic intensity varied in both time and space domains. The latter article also brought up an energy-saving algorithm to dynamically adjust the working modes (i.e., active or sleeping) of the BSs according to the traffic variation concerning a certain blocking probability requirement. Additionally, the BSs were set to hold their current working modes for at least a given interval to prevent mode switching that was too frequent. Simulations showed the proposed strategy could greatly reduce energy consumption with a guaranteed 28 preset blocking probability. In addition, the performance was insensitive to the mode holding time within a certain range. In [55], a practical implementation for approximating an energy-proportional (EP) 3G system by using non-EP BS components to cope with temporal-spatial traffic dynamics was presented. The article also proposed that the under-utilized BSs would be shut down and restarted again as needed. The network was divided into grids for each of the BSs. Each BS could replace some other BS for serving the MTs. Despite the significant energy savings in the overall cellular infrastructure, the authors also pointed out that the MT’s uplink transmission’s energy usage during the idle (e.g., late nights and weekends) hours was quite adversely affected.

3. ENERGY CONSUMPTION OF MOBILE NETWORKS TODAY

The main factor contributing to the increasing energy consumption is the prevalence of smartphones and tablets accessing the cellular network. Smartphones were introduced around 2000. However, about a decade later, the success of mobile operating systems such as iOS, Android, and Windows Phone finally helped them take over traditional feature phones. Tablet computers became popular almost simultaneously when the iPad Apple Inc. released the iPadelp, which had higher data transmission rates in 3G and 4G (and 5G in the future). Cellular networks, smartphones, and tablets enable users to perform many more tasks than ever when using cellular networks, e.g., streaming videos, downloading and reading e-books, web browsing, and social networking. As a consequence, both the number of mobile subscribers (4.5 billion in 2012, estimated 7.6 billion by 2020) and the amount of data traffic requested by each subscriber (on average 10GB per subscriber per year in 2012, estimated 82GB per subscriber per year by 2020) have increased explosively [12]. Also, more bursty and dynamic mobile data and video traffic replace mobile voice as the dominant traffic in cellular networks. These factors lead to significant increases in energy consumption. [56] showed that to provide the same level of coverage, an LTE network has to consume about 60 times more energy than a 2G network. More BSs, data centers, and other network equipment are required to support the growth in mobile traffic. Since BSs consume more than half of the total energy in a typical cellular network, the increase in BSs significantly impacts overall energy consumption [57], [10]. Relevant data in Figure 7 shows that the number of BSs worldwide has approximately doubled from 2007 to 2012, with today’s number of BSs today reaching more than 4 million [46], [47]. When cellular networks extend to remote districts or are deployed in developing or undeveloped regions, off-grid BSs must be deployed as no electrical grid is nearby. Off-grid BSs may cost ten times more to run than their on-grid counterparts, as they generally depend on fuel, a costly and unreliable power source [58 - 60]. On the other hand, hydrocarbon energy, one of the primary conventional energy resources that provide 85% of primary energy usage in the United States and releases large amounts of greenhouse gases when combusted, is proven to be not sustainable and is expected to be depleted in the foreseeable future [61]. The BSs serving small cells are known to have much less energy consumption than those serving macro cells. They have been deployed in densely populated areas or at the edges of existing macro cells to improve spectral and energy efficiency. However, due to the tremendous deployment of small cells in the foreseeable future, they will consume around 4.4 TWh of power by 2020, constituting an extra 5% of conventional macro cell networks [62], [63].

While the penetration rate of mobile phones in developed countries has exceeded 100%, in developing countries, the rising trend is rapid and still far from saturation [64]. For example, as of October 2013, China, the biggest developing market for telecommunications, had a 90% mobile phone penetration rate. Still, less than 30% of the population had access to 3G or more advanced networks [65]. All of these indicate a great potential for further growth of mobile data traffic and a corresponding rise in the trend of energy consumption.



Source: GSMA Research

Figure 10. Growth in the number of BSs (GSM Association 1999 – 2015) [58].

4. IMPORTANCE OF ENERGY SAVING IN OLDER GENERATION CELLULAR NETWORK

It is also worth noting that while we have reached the 4G (and beyond) era, 2G (GSM, GPRS, CDMA one, IS-95, EDGE, etc.) and 3G (WCDMA, HSPA, UMTS, EV-DO, etc.) networks are expected to coexist in the coming years due to their mature architectures, business models and lower price to subscribe. In particular, GSM is expected to remain in the foreseeable future in developing or undeveloped countries and remote regions where more advanced technologies are not cost-effective [66]. Moreover, the older generations of networks could always act as the “backup" network when higher standard networks are down or temporarily unavailable. On the other hand, carriers have announced plans for GSM spectrum refarming, which means phasing out currently used GSM services and reallocating the vacant frequency bands to wide-band network technologies such as LTE. It is considered one of the most cost-effective solutions for better-utilizing spectrums. However, it is a time-consuming process as it is difficult for carriers to shut down their entire GSM network immediately without any service interruption (especially for global roaming users). For example, Verizon, a US-based carrier, expects to work on the refarming process until 2021. Therefore, energy-saving technologies on 2G and 3G networks can still significantly impact the overall improvement in the energy efficiency of cellular networks in the future.

CONCLUSION

Developing green wireless communication systems is becoming more vital as wireless networks become ubiquitous. Green Wireless Communication will provide energy-efficient communication. It will result in less radiation from devices and more economic solutions for service providers and subscribers. Green wireless communication is part of Corporate Social Responsibility, which strives to reduce carbon footprint and Greenhouse gases to provide Green ICT services to customers. The government should also form rules and regulations to certify a service provider as a green service provider. Integrating energy-efficient technologies like Green BTS, Green manufacturing, Green Handover, Green antennas, green electronics, and Smart Grid solutions will create an accord between human beings and nature.

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