Energy efficiency and sustainability solutions for mobile networks

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Abstract— **This report aims to present a literature review about the current situation, challenges, and techniques of green mobile networks. By using paper from researches or analysis, this work analyses the motivation and the technologies to make mobile networks more energy-efficient and sustainable using cross information and analysis of research papers. The carbon footprint and energy cost are the main reasons why mobile networks need to be more energy-efficient. The development of many technologies (like massive MIMO) and network management techniques (like sleep scheduling) can contribute to achieving this goal even if there are still unknown about how these technologies can work together.**

Keywords— **Energy-efficiency, green communications, mobile networks, sustainability, wireless**

I. Introduction

Wireless networks support the connection of a variety of devices to be part of daily life, from mobile phones for communications, to emerging technologies and trends such as what is currently known as the Internet of Things (IoT). Nonetheless, the significant number of devices that use wireless networks, usually do not need to send and receive significant amounts of data. Thus, technologies may be adapted to be energy efficient under the required data rates and bandwidth. Additionally, finding a way to reduce their environmental impact becomes a challenge.

Energy efficiency and sustainability of wireless networks are critical subjects for mobile operators due to economics and environmental concerns. One crucial issue is the reduction of energy consumption on the transmission links with a significant reduction of the electrical expense. Additionally, the environmental issue is, of course, famous in the context of global warming. On the other hand, the expectative is that the number of wirelessly connected devices reach up to 50 billion; therefore the global carbon footprint of mobile networks is expected to reach around 235 Mto of CO_2 by the end of 2020[1]. Likewise, the development of the 5G network will increase worldwide energy consumption; 5G equipment consumes three times more electricity than a 4G, and its deployment will require three times more equipment compared to 4G.

Many solutions point out that decreasing the energy consumption of all the equipment and stages in communication contribute to energy efficiency (EE) in cellular networks. Some of the most effective techniques the authors highlight are baseband digital signal processing, adaptive traffic pattern, MIMO and OFDM. Similarly, cell-size deployment, adequate metrics and energy consumptions models on the design of antennas and radiofrequency. Optimization of the network is essential to reach energy efficiency, but energy sustainability is another point to address to lower the global footprint of the mobile network industry.

This report is composed of different sections. Section II shows the effects and requirements of mobile networks in terms of energy consumption. Section III reveals the challenges around reaching energy efficiency, and section IV summarizes the standard solutions that many authors propose to achieve energy sustainability, such as environmental energy harvesting or radio-frequency energy harvesting. Finally, information about research and future work is presented.

II. Energy consumption on wireless networks

The information and communication technology (ICT) sector has quickly developed because connectivity has become essential for interactions. This impressive growth causes the applications market to increase alongside with the number of people demanding wireless services and mobile data networks. What follows is a review on climate impact and energy consumption of wireless networks.

A. *Carbon footprint*

More than a decade ago, the Global Enabling Sustainability Initiative (GeSI) reported the first and one of the most important works about the ICT industry contribution for the low-carbon economy. The report predicted the carbon footprint of the ICT sector by 2020, stating that Mobile communication would issue more than half of them as Figure 1 shows.

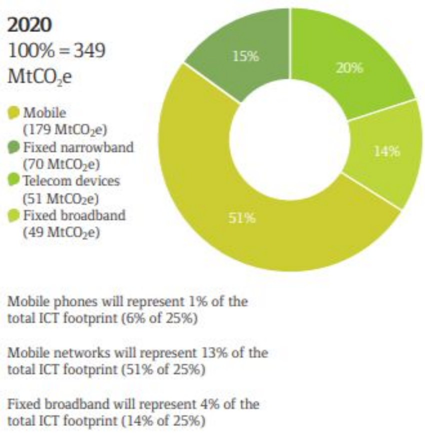

Figure 1. Forecast of global telecoms footprint [2].

The amount of data does not cause the overall carbon footprint of mobile networks. However, the rising number of worldwide mobile subscriptions since the infrastructure for mobile networks requires more radio base stations (RBS). Moreover, the small and low-power cellular base stations for home and small business environments, called femtocells, have become popular within the deployment of 5G mobile networks and might have an additional effect on the carbon footprint. The use of femtocells for sustainable wireless communication is discussed in section 4.

One crucial step to start decreasing the carbon footprint impact is calculating and monitoring the carbon production at each stage and component of the service. Although the communication elements are both mobile devices and network infrastructure, the mobile devices are not part of this review.

B. *Energy consumption*

According to [3], the expectative is that energy consumption from wireless radio access networks will increase by 2025, representing 50% of the overall energy consumption of communication networks. 5G networks do not only come with enormous performance improvements, but also drawbacks such as the degradation of EE.

Since the significant energy consumers in mobile networks are the RBS, the key metrics used by researchers are the energy consumption ratio (ECR) and the energy consumption gain (ECG), where:

$$ECR = \frac{Energy\ consumed}{Data\ bits\ communicated.}$$

ECR is measured in Joules per bit. Whereas,

$$ECG = \frac{Energy\ consumed\ by\ reference\ system}{Energy\ consumed\ by\ the\ system\ under\ test}$$

ECG denotes a considerable improvement in efficiency than 1 [4].

A synthesis of data made by Suarez et al. came up with an estimation of the energy consumption in the RBS. The power amplification stage is the biggest consumer, with approximately 60%, including feeder, transceiver power conversion, transceiver idling, and combiner/duplexing. The power supply, air conditioning and signal processing (analogue and digital) also consume significant energy with more than 10% each [5].

Although there is significant effort over the manufacturing stage in order to get more energy-efficient components for mobile networks, EE might also be improved by other performance strategies such as switching off the base stations when traffic is low, by extending the coverage area in a cell, increasing the signal bandwidth, or reducing the circuits.

III. Challenges for energy efficiency

The design of many solutions can contribute to improving the energy efficiency of a mobile network. To find these solutions, it is essential to have the right metrics and models of the energy consumption of such a network. The issue is to find the best optimization between methods and to see if it can be implemented.

A. Metrics and models

Choosing the right metrics and models is essential to analyze the network and see where EE can be improved, as shown in [6].

The most popular metric is 'bits-per-joule'. With metrics, power transmission seems as the primary constraint and the parameter to optimize is the number of bits with this amount of energy. This metric has been helpful to prove that the more nodes in the network and transmission time per bit, the better the network is in terms of EE. This metric is not perfect because it takes only into account the transmission power, which is not the only energy spent in the network. The energy circuit must also be taken into account. Having a too long transmission time per joule is not a good idea. A compromise must be found. Also, the headers of the packets must be taken separated because they are not real information bits. The impact of the headers in energy consumption must be studied separately.

Like metrics, models of energy consumption must be developed to utilize better the electricity spent in the network. A model of energy consumption in the base station can be one part of static energy and one part of dynamic energy. This model helped to show that for microcell base stations, the primary consumption is in the active part, and it is in the static part for the macro base station.

Having the right metrics and models is essential to take the whole network into account and avoid a reduction of energy consumption in one part of the mobile network and an increase in another.

B. Network management and deployment

The traffic load changes with time and localization during a single day. Parts of the network are then less used during specific timeframes but continue to consume energy, which is a waste. Managing the network to reduce this waste is a way to increase EE of the network. There are already some technologies to deal with changing traffic load like software called dynamic power saving (DPS). It can reduce the consumption of the base stations by 27% [6]. Moreover, switching off some cells when their traffic is low and can reduce the consumption up to 30%, but it is important not to switch cells too often because this may result in an efficiency loss.

To deploy new networks, it is essential to know many possibilities to make networks energy efficient. Also, the 5G network will soon be deployed around the world, and it is essential to make it more energy-efficient. As a result of much research, a dense network with a high data rate should deploy more micro-sites to be energy efficient. Also, picocells and femtocells installed in buildings are helpful to avoid penetration loss. The use of relays is also a way to design EE networks. Using packet scheduling and resource allocations networks with relays can improve the EE. Network coding technology helps to implement cooperative communication and reduce the number of transmissions and therefore, energy consumption.

C. Constraints

What are the challenges to realize methods to improve the EE of a mobile network? Some constraints may slow the developments of these green solutions, as shown in [7].

The cost is one of the first constraints to take into account. If EE is linked with a reduction in the electricity bill of the operators, it is also linked with an expensive cost of deployment. Heterogeneous networks are more expensive to install than previous techniques, for example. Moreover, introducing algorithms to reduce the power consumption will require more computational power and then increase the price of this equipment.

Another constraint to take into consideration is the spectrum efficiency. Controlling the power of transmission is directly linked with the data rate. It is essential to find a good compromise between quality of services and power saving to reduce the spending of power.

Bandwidth is another constraint. Green communications require ample bandwidth, but this requires new schemes and solutions to integrate it into the network. This field requires further analysis.

IV. Green wireless communications techniques

With the development of 5G, the environmental aspects of wireless communications have been discussed and studied at length. Several techniques were developed to face the challenge of green wireless communications, and some of them are discussed below.

A. *Sleep scheduling*

Base stations do not need to be active all the time, especially when the traffic is low in their coverage area. As described in [9], a possible solution to address this problem is sleep schedules. This technique consists of dynamically turning on and off individual base stations to meet the traffic variation in the network. Minimizing the number of active base stations saves a significant amount of energy.

B. *Renewable energies: using solar and wind energy hybrids systems*

According to [9], switching to renewable energies is an efficient way of reducing the carbon footprint of the telecommunication technologies, by, for instance, using solar and wind energy to power base stations. These types of energy resources are variable and depend on weather conditions. However, pairing them together in hybrid systems can lower this variability because it can rely on both wind and solar energy. Energy storage on-site can take over when there is no sun or wind and ensures that power is always available.

C. *Femtocells*

A femtocell is a small, low-power cellular base station, typically designed for use in a home or small business. According to [9] and [6], the use of femtocells allows network coverage in places where the signal to the primary network cells might be too weak, and it also reduces the total traffic travelling over the operator's extensive area radio, thus reducing the energy cost.

D. *Heterogeneous Networks*

A heterogeneous network is a network for which an area is covered simultaneously by cells of different sizes: macro-cell, micro-cell, pico-cell and femto-cell. Indoor picocells and femtocells allow a reduction in the penetration loss and path loss by bringing the receivers closer to the transmitters. According to [6] and [7], with these architectures, energy consumption can be significantly reduced. However, finding the best architectures for heterogeneous networks is challenging.

E. *D2D Communications*

Device-to-Device (D2D) communication in cellular networks is direct communication between two mobile users that do not traverse the base station. According to [7] and [8], using this technique increases the spectral efficiency and energy efficiency of the network. D2D communications reduce the latency of the communication, and the link is reliable. This technique helps to reduce the traffic that goes through a network and will allow more base stations to go into sleep mode, thus saving a large amount of power.

F. Massive MIMO

According to [6], [7], [8] and [9] Multiuser Multiple Input Multiple Output (MIMO) is a method used for multiplying the capacity of a radio link using multiple antennas in base stations to transmit and to receive, exploiting multipath propagation. In Massive MIMO a large number of antennas is used. This technique has many advantages, for instance: excellent energy efficiency, robustness, enhanced throughput, latency reduction and high capacity gains. The selection of the antennas is a crucial step. The antennas have to be energy efficient to control the power consumption at the level of the base stations. System architecture in massive MIMO can be optimized to reduce power consumption. Muting antennas is also a solution for this problem: muting an antenna in no-load or light load conditions can save about 50% of the power. Using this technique can reduce energy cost-effectively without altering the system performance.

V. Research and future work

5G deployment has demanded the study of solutions for EE alongside the architecture to support capacity and high data rates. Most of the research is going through reducing energy consumption by optimizing the design of the transmission, resource management, and network deployment. Since interference and randomness are features that affect 5G networks, sequential, functional programming, and new statistical models are promising and suitable for resource allocation, monitoring and rethinking of the network behaviour.

The backhaul transmission and digital signing processing should be associated with new energy consumption models. Moreover, EE might take advantage of emerging technologies, such as caching and mobile computing. Not much effort has been put on the understanding of these techniques, which can result in a relative reduction of energy consumption or extending the lifetime of low-battery devices [8].

VI. Conclusions

Mobile networks have overgrown due to the increasing demand for connectivity. Today their carbon footprint and energy consumption are concerning, even more with the upcoming worldwide deployment of 5G. To make a mobile network energy efficient and energy sustainable, it is essential to know better the distribution of power consumption in the network and how different parameters influence its consumption. Many methods have been developed to help mobile communication be energy efficient, but there are still some uncertainties about how efficient those methods are using them together.

References

[1] Fehske, A., Fettweis, G., Malmodin, J., & Biczok, G. (2011). “The global footprint of mobile communications: The ecological and economic perspective”. IEEE Communications Magazine, 49(8), 55–62. https://doi.org/10.1109/MCOM.2011.5978416

[2] E. Farnworth and J. C. Castilla-Rubio, "SMART 2020: Enabling the low carbon economy in the information age," 2020.

[3] J. Lorincz, A. Capone, and J. Wu, “Greener, Energy-Efficient and Sustainable Networks: State-Of-The-Art and New Trends,” Sensors, vol. 19, no. 22, 2019.

[4] P. Grant, "Green Radio – The Case for More Efficient Cellular Base Stations," Mob. VCE, no. May 2009.

[5] L. Suarez, L. Nuaymi, and J. M. Bonnin, "An overview and classification of research approaches in green wireless networks," Eurasip J. Wirel. Commun. Netw., vol. 2012, pp. 1–18, 2012, DOI: 10.1186/1687-1499-2012-142.

[6] Feng, D., Jiang, C., Lim, G., Cimini, L. J., Feng, G., & Li, G. Y. (2013). “A survey of energy-efficient wireless communications”. IEEE Communications Surveys and Tutorials, 15(1), 167–178. https://doi.org/10.1109/SURV.2012.020212.00049

[7] Malik, N. A., & Ur-Rehman, M. (2017). “Green communications: Techniques and challenges”. EAI Endorsed Transactions on Energy Web, 4(14). https://doi.org/10.4108/eai.4-10-2017.15

[8] S. Buzzi, I. Chih-Lin, T. E. Klein, H. V. Poor, C. Yang, and A. Zappone, "A survey of energy-efficient techniques for 5G networks and challenges ahead," IEEE J. Sel. Areas Commun., vol. 34, no. 4, pp. 697–709, 2016, DOI: 10.1109/JSAC.2016.2550338.

[9] Kumar, A., Liu, Y., Singh, T., & Singh Khurmi, (2011) “Sustainable Energy Optimization Techniques in Wireless Mobile Communication Networks” The First International Conference on Interdisciplinary Research and Development, June, 1–6.