5G network energy efficiency

Massive capacity boost with flat energy consumption
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Introduction

Energy consumption is a major contributor to network operating expenditure (OPEX) and also has an impact on CO\textsubscript{2} emissions. In developing economies, almost a quarter of new cell sites will be beyond the power grid. The implementation of renewable energy and more energy-efficient equipment can bring significant benefits by helping operators to deal with unpredictable fuel prices.

In mature markets, up to 15 percent of network OPEX is spent on energy. In developing markets, this can vary typically from approximately 15 percent up to 30 percent of network OPEX. Nokia aims to keep mobile network energy consumption flat or even to decrease it, while increasing network capacity substantially. By 2030 there is likely to be as much as 10,000 times more wireless data traffic criss-crossing networks than there was in 2010. This capacity will be required to serve the very high traffic volumes created by extreme mobile broadband with higher data rates, massive Internet of Things (IoT) connectivity and critical communications running on top of mobile networks.

There is much potential for improving the energy efficiency of traditional mobile networks. Just 15 percent of the energy spent on operating a network is used for forwarding bits, which means that 85 percent of the energy does not contribute to generating revenue.

Although 80 percent of the energy is consumed by base stations, over a 24 hour period base stations will spend most time sitting idle and not transmitting. Therefore, most energy is used for system broadcasts and running idle resources; to power fans and cooling systems; for heating and lighting; and to run uninterruptible and other power supplies. There is real potential to reduce these secondary uses of energy to substantially improve a network’s overall energy efficiency.

Nokia has high targets in energy efficiency and also promising solutions. Energy efficiency is a key requirement during the research and standardization of 5G networks. There is additional energy-saving potential in the replacement of deployed 2G/3G/4G technologies, using multi-standard equipment and virtualization, shifting of traffic to 5G, and refurbishment of radio frequencies.

Modernizing networks helps to keep total power consumption flat by minimizing the use of energy not directly related to data transmission. Figure 2 quantifies the gain that can be achieved by using improved base station products that operate without cooling.

This white paper describes the major opportunities, as well as the principle methods of achieving the energy efficiency target.
Figure 1. Electricity is typically 15 percent of the network OPEX. Base stations take 80 percent of mobile network energy.

Cooling takes >50% of the energy.

Figure 2. Minimize power consumption of auxiliary equipment.
Energy saving opportunities

There are several major opportunities for improving the energy efficiency of base station sites:

• Reduce the energy consumption when the base station has no data to be sent
• Reduce the energy consumption due to the auxiliary equipment
• Increase hardware efficiency, particularly when operating below maximum power.

We have learnt from a large number of live LTE networks that the average use of air interface resources in highly loaded networks is typically 20-25 percent. There are clear reasons for such a low average utilization:

• The traffic is not equally distributed between base stations
• The traffic is not equally distributed over a 24 hour period.

If the average usage is higher, busy areas during the busy hour become congested. The traffic distribution over the whole network is illustrated in Figure 3. 50 percent of the traffic is typically carried by 15-20 percent of the base stations, and 80 percent of the traffic by 30 percent of the base stations. Therefore, the remaining 70 percent of base stations only carry 20 percent of the traffic and their utilization is low. The main reason for unequal traffic distribution is the coverage requirements - networks need to provide coverage in those areas where traffic density is low. There is a clear opportunity to improve the network's energy efficiency in these low load areas.

Figure 3. Typical traffic distribution over the whole mobile network
The traffic distribution over a 24-hour period is shown in figure 4. Busy hour typically takes place in the evening and carries 6-7 percent of the daily traffic. This means the busy hour carries 60-70 percent more traffic than an average hour and substantially more traffic than low traffic hours during the night. There is a clear opportunity to improve the network’s energy efficiency during the low load periods.

**Base station sleep mode**

During periods of no activity, the base station can minimize its energy consumption by going into sleep mode. The duration of the sleep mode is limited in LTE radios because reference signals need to be transmitted four times in every 1 ms period. Consequently, LTE allows only for very short sleep modes called micro-Discontinuous Transmission (μDTX), which may turn off the power amplifier for only up to three signal periods even if there is no user data.

With a more flexible reference signal design in 5G, it will be possible to make better use of sleep mode and achieve more power savings. The base station power consumption with and without data traffic is illustrated in Figure 5, assuming the level of technology implementation in the year 2020. The potential reduction in the power consumption with 5G radio compared to LTE is expected to be 30-70 percent, at typical load levels of between 5 percent and 20 percent.
Small cell energy efficiency

Small cells can enhance network capacity and also energy efficiency by delivering high capacity with low transmission power leading to low power consumption. Small cells will become an important part of mobile networks because the lower coverage at high frequencies requires high cell density, as does high capacity.

Figure 6 illustrates small cell power consumption. The transmission power is assumed to be 2x5W. The power consumption is approximately ten times lower than in the macro cell, clearly enabling higher energy efficiency per bit. The 5G baseband protocol design and small cell implementation needs to focus on the baseband power efficiency in addition to the RF efficiency, in order to minimize the total base station power consumption.

Even if the power efficiency of a single base station improves, this does not compensate for the high density of the small cells. Therefore, there is a clear need to have new system level solutions to minimize power consumption.

Figure 5. Base station power reduction potential at low loads in LTE and in 5G
Since small cells cover only limited areas, it is highly likely that there are no users in some of the small cells at certain times outside the busy hours. One option is to switch off unused small cells. It is still important to maintain the network coverage area and be able to switch the cell on again when needed. An example case is shown in Figure 7, where the macro cell provides full coverage and the small cells can be switched off when there are no users or low number of connected users.

Switching off small cells brings an additional benefit in terms of minimization of inter-cell interference. The ability to switch small cells on and off is already supported by LTE networks and will also be used in 5G deployments.

Figure 6. Small cell power consumption with different loads in LTE and in 5G

Figure 7. Small cell on/off switching
Network level energy efficiency

We can estimate the network level energy efficiency when considering new power saving solutions with sleep modes and taking into account efficiency improvements in power amplifiers. We calculated a scenario for a European operator. The principles for calculation are that total annual traffic is growing by 58 percent annually (i.e. tenfold every five years), subscribers move to a new technology at the current rate and the operator makes maximum use of existing macro cell sites. 5G is launched in 2020.

The results are presented in Figure 8. 4G eventually has at least four frequency bands and 2G and 3G would ultimately operate only on the 900 MHz band. 5G would have at least two bands below 6 GHz, altogether around 80-100 MHz for downlink and possibly a higher band.

Currently, most energy is still used on 2G and 3G, even though sites would have been modernized. 4G is growing rapidly and needs brisk investment until the early twenties. We assumed that 3G or 2G can be switched off in 2021, with one of these legacy radios left operational until 2025, for example to support Internet of Things (IoT) machine type communication using narrowband 2G. It is also assumed that energy saving features are implemented in 4G that reduce power progressively by 25 percent during 2020 - 2025. It is expected that the 4G macro cell network becomes fairly congested in dense areas around 2020, which provides the motivation to deploy small cells, but from the energy point of view they remain in a clear minority in 4G. Small cells are assumed to have output power of 5+5 W. In the calculation it is assumed that with all networks, 2G-4G, unused capacity is removed from the network with declining traffic.

Transmission of broadcast or reference signals is assumed to be minimized in 5G, which would enable base stations to employ sleep modes to save energy. Beyond 2025, it seems likely that macro cellular 5G will not be able to satisfy all traffic demand, so small cell deployments need to be assumed. It is also assumed that indoor systems carry a significant part of 5G terminals by 2025 - this energy is not counted since the figure only presents energy costs for the wide area network operator. The calculations show that we can be confident that operators will be able to reduce their power consumption in the future.

![Figure 8. Total network level power consumption](image-url)
Figure 9 shows energy efficiency calculated for the assumed scenario. 5G offers an advantage over 4G, with its wider bandwidth, more advanced antennas and base station sleep modes. The difference between macro cell and small cell layers comes from the ten times difference in output power and from the fewer simultaneous users to be served by small cells.

The rise of 4G energy efficiency during 2015-2020 is due to early network deployments, which, motivated by the need for coverage, become more capacity limited by the 2020s. 5G macro cellular has higher efficiency from the start due to very small energy consumption in low traffic conditions.

**Summary**

The energy efficiency of mobile networks can be significantly improved by using 5G power saving features, by small cell deployments and by new 5G architecture and protocols.

5G has a significant potential for reducing energy compared to LTE by using sleep modes at low load - up to 50-60 percent gains at the base station level when networks operate at 10 percent average load, and up to 30-40 percent gains at 20 percent average load. Also, the hardware technology, in particular RF, is expected to improve the energy consumption of both LTE and 5G macro base stations.

An example hardware innovation is Nokia AirScale, which uses up to 60 percent less energy than the existing market-leading Nokia products.

Low power small cells can further reduce the required energy to deliver mobile data to customers by minimizing the energy consumption per gigabyte.
Using all the approaches described, network operators can upgrade their networks for the expected traffic growth with a sustainable energy cost - even with heavy traffic growth. The overall network energy consumption in the evaluated network scenario has the potential to remain flat between 2015-2025. Nokia can clearly take operators on a journey to a greener world.

Further Reading

Nokia Flatten energy consumption white paper:  

GreenTouch white paper
(This white paper uses the operator data provided by GreenTouch, an initiative by Nokia Bell Labs)

Nokia AirScale radio access portfolio:  

Nokia investing in improved base station power efficiency:  