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Published in:
Vehicular Technology Conference (VTC Fall), 2013 IEEE 78th

DOI (link to publication from Publisher):
10.1109/VTCFall.2013.6692299

Publication date:
2013

Document Version
Early version, also known as pre-print

Nation-Wide Mobile Network Energy Evolution Analysis

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Abstract – **Mobile network operators are facing a challenging dilemma. While on the one hand they are committed to reducing their carbon emissions, and energy consumption, they are also required to continuously upgrade existing networks, ensuring that the relentless growth in data traffic can still be supported. In most cases, these upgrades increase the energy consumption of the network even further. This paper presents a nation-wide case study, based on a commercial network of a leading European operator, intended to provide a clear understanding of how the energy consumption of mobile networks is expected to evolve from 2012 until 2020. The study also considers an efficient network capacity evolution path, including base station equipment improvement forecasts.**

Keywords-component; energy saving, network evolution, energy efficiency, equipment replacement, base station site, heterogeneous network.

I. INTRODUCTION

Over the last decade practically all industries have hopped onto the green bandwagon, attempting to, where possible, reduce or offset carbon emissions. With carbon emissions closely related to the energy consumption, mobile network operators (MNOs) around the world are attempting to optimize and run their networks more efficiently. In addition to regulations and guidelines [1] set by the European Commission (EC), a number of MNOs have gone further, committing to even more ambitious targets. Further reductions in consumption have the added benefit of also reducing energy related costs which have over the past years continued to soar. Statistics on the industrial unit price of energy within the European Union (EU) show that in the last three years this has increased annually at a rate of 8.5% [2].

While beneficial for MNOs to operate networks more efficiently, a further pressing and opposing challenge is the growing demand for mobile broadband. Over the last years, the volume of traffic carried by mobile networks has been increasing exponentially [3]. This growth, predicted to maintain an average yearly growth rate of around 78% (up until 2016), is mainly driven by an increase in the number of mobile devices as well as an increase in the volume of data consumed per device category [3]. In order to sustain such a steep growth in data traffic MNOs are required to forecast and upgrade network capacity. In addition to upgrading existing base station sites with further carriers (if spectrum is available), MNOs can also boost network capacity by deploying additional macro sites, small cells, and/or an entirely new radio access technology (RAT), with Long Term Evolution (LTE) being the next fresh layer. In most of the cases such upgrades require the installation of additional base station equipment, more processing, or higher output power which increases further the energy consumption of the site and hence the network, making the objectives of reducing consumption and emissions much more challenging.

By considering a nation-wide commercial network, this paper provides a comprehensible investigation on how its energy consumption is expected to evolve. By focusing on the radio access part of the network, this study includes and considers an energy efficient capacity evolution path, and the potential savings of replacing aging equipment with more modern and efficient versions. Due to the fact that a fully-fledged network with all three RATs is considered, this paper presents MNOs and the research community alike a novel and holistic overview on which network areas, layers, and technologies are primarily responsible for the energy consumption within mobile networks.

II. NATION-WIDE CASE STUDY

A. *The Network*

A nation-wide European network is considered as a case study to evaluate the expected evolution in energy consumption of mobile networks. Within such an extensive area, the network is made up of distinct regions with different site densities, deployed RATs per site, carrier configurations, traffic profiles, etc. Due to these heterogeneous conditions, this study categorizes the network into three main areas. These are defined according to the average inter-site distance (ISD) between neighboring sites: urban (neighbor sites closer than 350m), suburban sites (neighbor sites at the range between 350m and 1700m) and rural sites (neighbor sites farther than 1700m). Furthermore, for each area, the most common site configurations, deployed RATs, and traffic profiles are identified. This differentiation allows for specific upgrade strategies being applied as necessary to the considered areas.

B. *Capacity evolution*

Due to the expected increase in traffic illustrated in Figure 1 [3], a number of research studies [4] (and references within [4]) have looked at the possible options for MNOs to upgrade existing network infrastructure. In many, the adoption of small cells and the transition towards a heterogeneous cellular network seems to be a favorable option. In comparison to adding more macro cells, small cells (both indoor and outdoor) have the added advantage of concentrating capacity over small areas, making them ideal for serving a hotspot of traffic. In addition to providing additional capacity, small cells also provide an offloading mechanism for surrounding macro sites [4], reducing the extent to which such sites need to be upgraded.

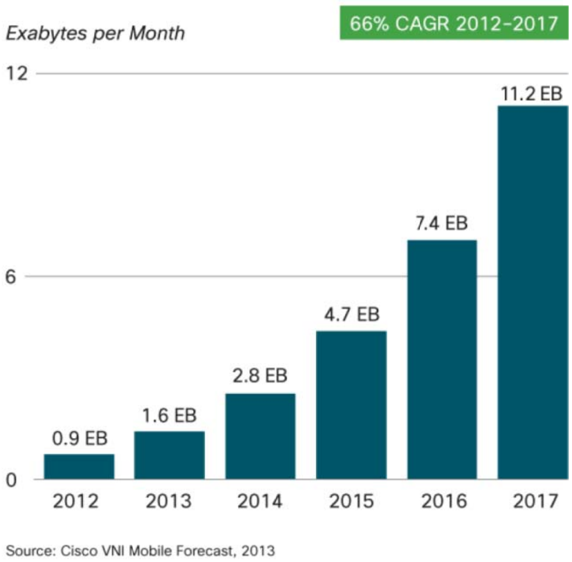

Figure 1- Traffic forecast 2012-2017 [3].

Network capacity evolution studies, primarily focused on urban areas, have shown that the ideal method, in terms of performance [5] and energy [6], of upgrading an existing network is that of adopting a hybrid approach [4]. In addition to deploying small cells in hotspot areas – also often referred to as capacity expansion aid – existing macro sites can be upgraded with more carriers in case enough frequency spectrum is available. Based on the outcome of previous studies [6], traffic statistics extracted from the considered European network, and discussions with the operator, a set of network upgrades is assumed for the different network areas for the evolution of the network until the year 2020. Considering only the extent of macro upgrades for the existing sites, Table 1 provides an overview of how these upgrades are carried out, indicating the number of carriers or transceivers needed per RAT to meet the capacity requirements. It should be noted that 95% of the urban sites will need to be upgraded with a second LTE carrier to meet the capacity growth demand.

	Urban				Suburban				Rural			
LTE carriers	2012	2015	2018	2020	2012	2015	2018	2020	2012	2015	2018	2020
1	0%	40%	50%	5%	0%	40%	60%	15%	0%	20%	50%	80%
2	0%	10%	50%	95%	0%	10%	40%	85%	0%	0%	0%	0%
UMTS carriers	2012	2015	2018	2020	2012	2015	2018	2020	2012	2015	2018	2020
1	22%	0%	0%	0%	62%	20%	0%	0%	82%	50%	20%	0%
2	75%	50%	20%	0%	35%	50%	20%	0%	18%	50%	80%	100%
3	3%	40%	50%	50%	3%	20%	50%	50%	0%	0%	0%	0%
4	0%	10%	30%	50%	0%	10%	30%	50%	0%	0%	0%	0%
GSM TRXs	2012	2015	2018	2020	2012	2015	2018	2020	2012	2015	2018	2020
2	9%	0%	0%	0%	23%	10%	0%	0%	85%	30%	0%	0%
3	7%	0%	0%	0%	22%	10%	0%	0%	9%	40%	30%	0%
4	84%	100%	100%	100%	55%	80%	100%	100%	6%	30%	70%	100%

Table 1- Capacity upgrades per technology: Percentage of sites for each configuration from 2012 to 2020.

Apart from the capacity upgrades of the existing macro sites, including carrier upgrades and LTE deployments, additional small cells are required in order to cope with the exponentially increasing traffic volumes. Table 2 illustrates the number of small cells required per macro site. The location of deployed small cells is based on the considered type of area, with most of the small cells deployed within urban areas, and some of them in suburban areas. The number of deployed small cells is estimated in such a way that the deployed small cells together with the macro upgrades meet a predetermined increase in network capacity. In this regard, a 25x increase in network capacity until 2020 is assumed in Table 2.

	Urban				Suburban				Rural			
LTE	2012	2015	2018	2020	2012	2015	2018	2020	2012	2015	2018	2020
Small cells	0	2	4	5	0	0	1	1	0	0	0	0
UMTS	2012	2015	2018	2020	2012	2015	2018	2020	2012	2015	2018	2020
Small cells	0	2	3	3	0	0	1	1	0	0	0	0

Table 2 - Deployment of LTE/UMTS small cells (number of small cells per macro site).

C. *The Equipment*

A crucial factor which must be considered in order to accurately analyze the energy efficiency of a network is the age and type of the equipment installed. Improvements in base station equipment are not only limited to increasing the processing power to meet capacity needs, but have, in recent years, also focused on reducing their energy consumption. Despite the fact that hardware replacement brings an extra cost to the MNO, in the long run, it is a key strategy to reduce the network energy consumption while improving the customer experience at the same time.

The energy consumption has been calculated using a model which considers the different hardware versions of the different elements of the base station (radio module and system module). It should be noted that each configuration requires different modules, and also the different capacity upgrades will require to swap or to increase the number of some of these modules.

Operators are likely to replace base station equipment based on the need for new/enhanced set of features, the age of the current equipment, and the necessary capacity expansions. Figure 2 represents the assumed mixture of different equipment versions for each RAT, and the respective evolution along the time. The assumption is based on a reasonable tradeoff between bringing new equipment into the network and the costs of replacement. The considered life cycle of each hardware version is around 5 years, with Ultrasite version being the oldest one, and Flexi Release 5 the dominant equipment release predicted for 2020.

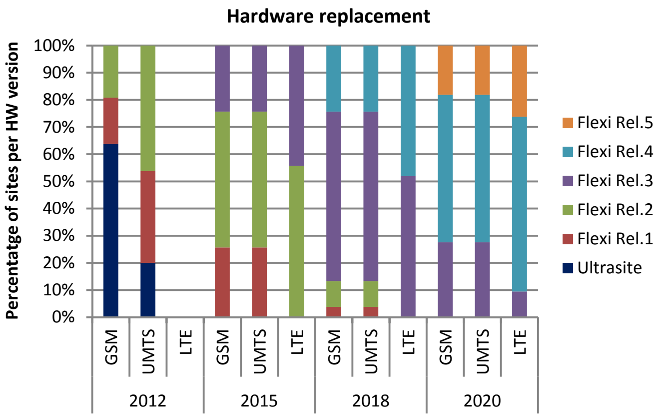

Figure 2 - Overview of the replacement strategy of base station equipment assumed over the investigated time period.

For the sake of completeness, this study is considering three different types of radio modules:

- Radio Module (RFM): A box consisting of three power amplifiers that can be used to build a three-sector site with only one module. Latest versions are equipped with six power amplifiers which allows e.g., to deploy 2x2 MIMO configuration in a three-sector site with only one radio module
- Remote Radio head (RRH): A radio module consisting of two power amplifiers. One box per sector is required allowing for up to 2x2 MIMO configurations.
- Active Antenna System (AAS): A disruptive antenna system consisting of vertically distributed radio units and associated signal processing intelligence allowing for advance beamforming techniques such as vertical sectorization.

Figure 3 provides an overall view on the different radio module types assumed for each of the different areas along the considered period.

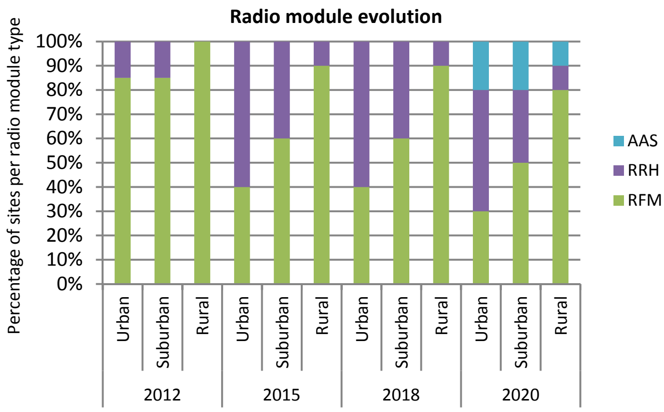

Figure 3 - Overview of the replacement strategy of radio module versions assumed over the investigated time period.

D. Other assumptions

The study also assumes that the number of macro sites remains unchanged along the years, just considering SW and HW upgrades for the existing ones. Where necessary, the deployment of small cells is carried out as described in the Capacity evolution section.

For the years ranging from 2018 to 2020, the concept of network sharing (NS) has also been considered. NS permits two different MNOs to share network equipment, allowing each MNO to own a certain percentage of the total number of sites. In our analysis we considered that the network from 2018 onwards is shared equally, i.e. assuming a 50/50 share. It should be noted that each site has to be capable of supporting the frequencies and traffic of both MNOs, generally requiring extra equipment and capacity per site. NS is expected to result in considerable savings for MNOs [7] and its benefits regarding energy consumption reduction will be evaluated in this paper.

The study also considers different traffic patterns based on the time of day as well as the type of area. This is important because the energy consumption of base station sites varies with the traffic load. In general the site equipment is more energy efficient during periods with high traffic than during periods with low or without traffic. Therefore, the base station energy consumption based on the actual traffic load is taken into account.

Finally, the following assumptions in terms of output power are considered. We assume a transmission power of 10W per transceiver for GSM, and 20W per carrier for UMTS. In case of LTE with 2x2 MIMO configuration a transmission power of 40W is assumed which equally split between the two transmission chains (20W+20W). In the same way, different bandwidths have been considered for the different radio technologies: 200kHz per transceiver for GSM, 5MHz per carrier per UMTS and 10MHz per carrier for LTE.

III. RESULTS

Based on the current information of the considered nationwide network, the estimated evolution for the following 8 years and the above assumptions, the network energy consumption evolution is calculated and a number of interesting trends are shown in the following. Let us first discuss the variations in the overall consumption. Over the period considered, the network energy consumption, presented in Figure 4 can be split into two main periods.

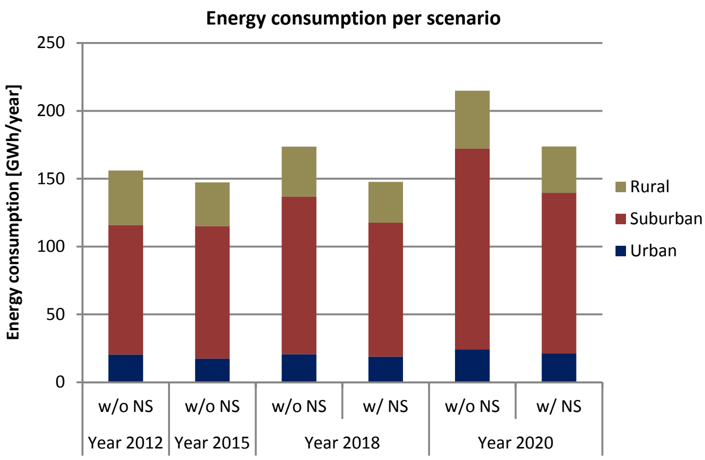

Figure 4 - Energy consumption of the entire radio access network.

From the year 2012 until 2015, the overall network energy consumption is observed to decrease by about 6%. This reduction in energy consumption is achieved although the capacity of the network is increased by four (Figure 6), particularly with co-sited deployment of LTE prior to the year 2015. The main reason for this reduction in energy consumption is the replacement of old base station equipment with modern equipment that consumes considerably less energy. The results consider an intermediate[1] replacement strategy (Figure 2). The focus of this strategy is to remove legacy equipment in an efficient way, allowing to increase the available capacity to meet the traffic demand and to decrease the energy consumption, but at the same time controlling the overall expenses.

From 2015 onwards, the trend is reverted. Even in NS scenarios, the energy consumption is noted to increase. While newer and more efficient base station equipment continues to be deployed, the necessary HW expansions and the deployment of small cells required to support the forecasted traffic growth yields an overall energy consumption increase.

Figure 4 also depicts how the energy consumption is evolving in the different scenarios. Results show that most of the energy is consumed in suburban regions. While the density of macro sites in urban regions is considerably higher, suburban regions cover a larger area. In our study the number of macro sites in suburban areas is 3.5 times higher than in urban areas. This leads to suburban areas being accountable for more than 60% of the overall energy consumption, whereas urban and rural areas consume only for around 20% and 25%, respectively. This indicates that it is not only important to optimize and reduce the energy consumption of urban sites. Dedicated improvements and/or optimizations for suburban and rural sites can also considerably contribute to the overall reduction of the energy consumption.

Figure 5 shows the energy consumption evolution per RAT. It can be observed that the energy consumption of UMTS and GSM is reduced year over year while the LTE consumption increases. This reduction of the GSM and UMTS consumption is due to hardware improvements, despite the fact that the network capacity is continuously upgraded. The increased contribution of LTE to the energy consumption is due to the large deployment of this new technology across the whole country. Figure 5 also illustrates the benefits of NS from 2018 onwards. This efficient sharing of the equipment allows for reducing the energy consumption around a 20%.

[1] By contrast, an aggressive strategy assumes that all equipment is replaced with the newest version available. This obviously reduces the energy consumption on the one hand, however on the other hand increases the overall expenses.

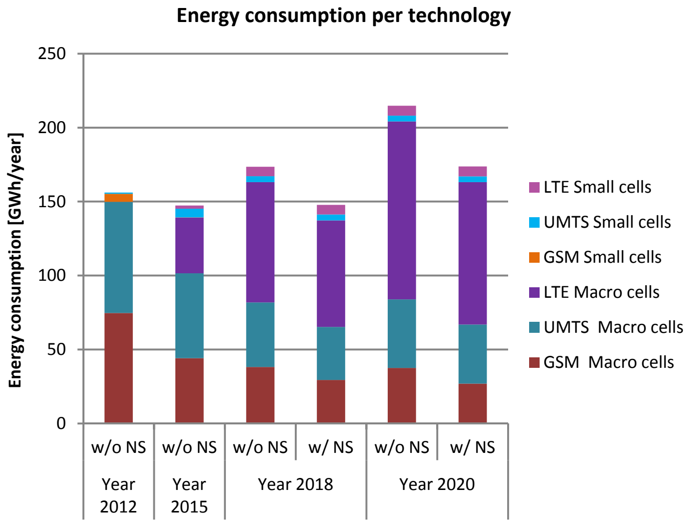

Figure 5 - Energy consumption evolution per RAT.

Finally, Figure 5 also shows the contribution of the small cells to the overall energy consumption. Compared to macro sites, small cells only account for a 6% of the total energy consumption. This is due to their low power consumption and high energy efficiency.

Besides the network energy consumption evolution, it is important to also study the data consumption trends and their relation to the energy consumption. The estimation of the data volume evolution depicted in Figure 6 is based on the assumed capacity upgrades, and the expected evolution of the spectral efficiencies of each technology over the years.

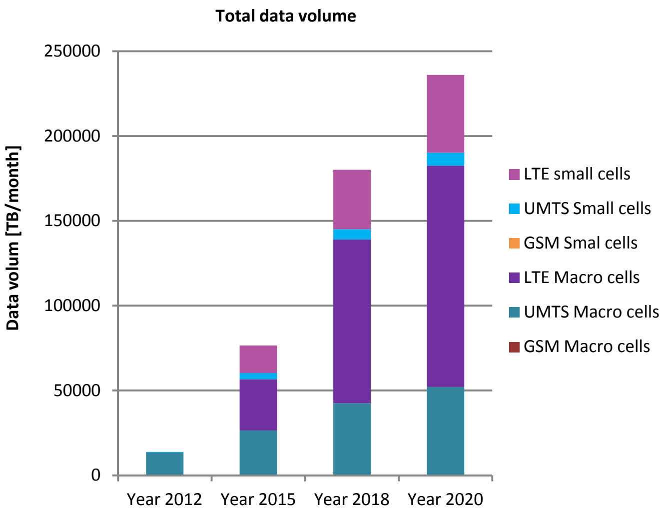

Figure 6- Estimated evolution of the data volume per RAT.

Although as seen in Figure 5 LTE was the most energy consuming technology, Figure 6 also shows that LTE is the technology contributing the most to the total network capacity, approximately 75% of the total capacity. On the contrary, GSM contribution is almost negligible due to the lower data rates GSM is able to provide compared to LTE. Therefore, GSM is mainly used for voice traffic.

The benefits of small cells can be seen by comparing Figure 5 and Figure 6. While the contribution of the small cells to the total energy consumption is very small (6%), the contribution to the data volume is considerably higher (22%).

The previous results showed the evolution of the energy consumption and data volume, but it is also important to evaluate the relation between both of them. There is always a tradeoff between the energy consumption reduction and the needed capacity upgrades to cope with the expected traffic demand. Figure 7 shows the energy efficiency evolution in terms of energy required in order to transmit one terabyte of data.

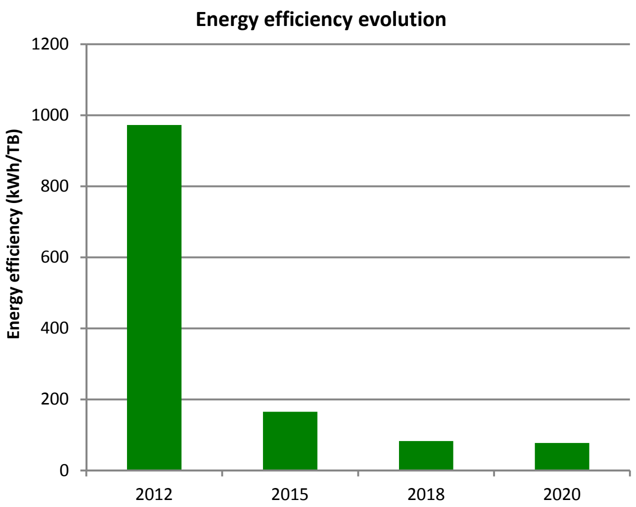

Figure 7- Estimated evolution of the energy efficiency.

Although the energy consumption was observed to increase from 2012 until 2020, there is a significant improvement in the energy efficiency: approximately 1000 KWh are required in 2012 for each terabyte of data, whereas in 2020 it is only around 60 KWh, i.e. the energy efficiency is 15 times higher in 2020.

IV. Summary and Conclusions

Due to the exponentially increasing traffic demand, mobile networks need to be continuously upgraded, i.e. both new features to improve the spectral efficiency as well as additional frequency spectrum by means of more carriers and TRXs are required. Furthermore, new RATs, such as LTE, as well as small cells should be deployed to cope with this high traffic demand. On the one hand, these capacity upgrades and new deployments come at the price of further increasing the total energy consumption. On the other hand, however, the evolution of the hardware is not only allowing to obtain more capacity and a better user experience but also reducing the energy consumption per transmitted bit.

The holistic overview of the energy consumption trend of a nation-wide European radio network illustrated in this study shows a 10% increase in the total energy consumption, assuming a 25 times increase in the network capacity by 2020. Most interesting, however, is the fact that the overall energy efficiency improves by 15 times in 2020 compared to 2012. The results clearly identify the areas which consume more energy, enabling mobile network operators, vendors and the research community to focus on these areas.

The study also shows the impact of the different equipment versions, the impact of the small cell deployment, and the deployment of new RATs, such as LTE, which increase slightly the total energy consumption, also provide a considerable contribution to the total network capacity required to meet the traffic demand.

V. Future Work

The estimated energy consumption trend of an European nation-wide radio network in this paper provides a good framework on top of which promising energy saving features and concepts as well as economical aspects can be investigated. The impact of energy saving features, such as shutting down of carriers, RATs, etc. on the overall energy consumption will be analyzed in detail in the future.

The study can be also used as a baseline to evaluate the impact of the different upgrade strategies on the energy consumption trend, for example, comparing a conservative with a more aggressive small cell deployment or different LTE introduction strategies.

Furthermore, a more detailed economic analysis with respect to the equipment replacement is part of future work, considering the trade-off between equipment costs, new feature functionalities and energy savings.

VI. Acknowledgements

The authors would like to thank Stefan Voss, Helmut Heinz, Andree Haubrich and Giovani Siqueira from Nokia Siemens Networks for the information and useful insight provided along the study.

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