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Research Memo

10-year evolution of 5G energy efficiency

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Executive summary

This paper gives a global overview about the energy efficiency evolution of mobile networks including 5G (@3.5 GHz). We will describe the main improvement levers of infrastructure energy efficiency based on the measurements in our labs and on our industrial collaborations with our suppliers.

Per Gbyte of data traffic, 5G has the potential to reduce the network energy consumption (compared to 4G) by a factor 2 at launch, by a factor 10 by 2025-2030 and by a factor 20 by 2030-2035 (see Fig. 1). Most of these improvements would not be achievable in 4G, which would anyway be congested in big cities in the coming years. Indeed, if the traffic growth remains at the current rate of about 40-50% per year, we can expect between x30 and x60 more traffic by 2030.

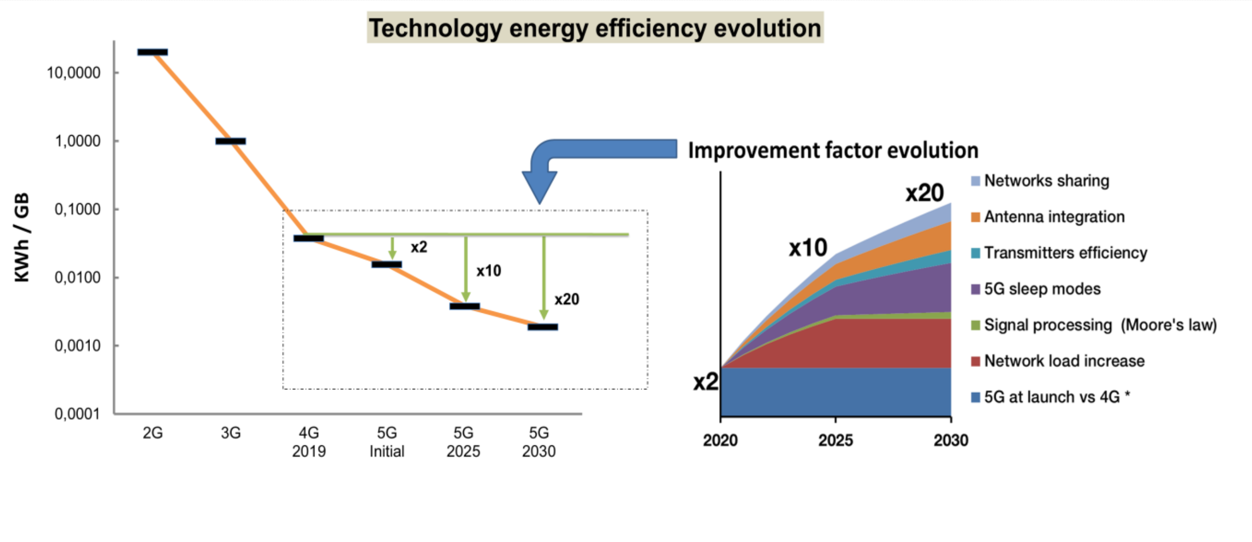

Fig. 1. Technology energy efficiency evolution

In this context, stabilizing the energy consumption of our mobile networks is an achievable but very challenging target.

As in previous wireless generations, energy efficiency gains are gradual as deployments progress and equipment improves. These gains are multiplicative and will take place throughout the life cycle of 5G: the x10 gain for 5G compared to 4G is reasonable by +2025. The timing and values of these gains are not yet exactly known as they depend on many factors (sourced equipment, traffic loads, frequency bands, etc.).

It is also fair to say that the same x10 gain has been reached by the legacy generations (2G→3G→4G).

Analysis of energy efficiency evolution

First of all, in a mobile network 80% of the operation energy is consumed in the access (i.e. base station antenna sites). Our analysis is therefore based on inputs from our industrial collaborations with Radio Access Network (RAN) suppliers and our current lab tests and trials in 5G cities.

Measurements show that, at low load, 5G will be x2 more energy efficient than 4G. Nevertheless, a realistic expert projection allows us to be more optimistic about the evolution of 5G energy efficiency. We think it is reasonable to count on a factor of x10 (at least) between today and 2025-2030 based on the levers identified in Fig. 1, and that we will explain in the next section.

Please note the following remarks about the methodology we have used in our analysis.

Note 1: 2G, 3G and 4G data are collected from field measurements in Orange networks everywhere. Energy and corresponding traffic are now available in many affiliates thanks to the deployment of measurement systems (ELECTRA project and others). The magnitudes can change from one country to another depending on the climatic conditions, the generation of equipment and the volume of traffic. For example, Orange Poland networks consume 0.07 KWh / GB in 4G and 20.8 KWh / GB in 2G while Orange Romania has an equivalent 4G energy efficiency but consumes 30.2 KWh / GB in 2G.

Note 2: The starting point may vary depending on the 5G launch year. We have considered here a starting point at 10% load. Lab measurements are performed according to ETSI 202-706 (2014).

Note 3: Some levers like antenna integration depend exclusively on RAN suppliers. The evolution trajectories are then issued from our discussions (under NDA) with chipset providers like NXP.

Note 4: the comparison only takes into account the telecom part. The technical environment has not taken into account because it is shared between all technologies.

Improvement factors

This section presents the 5G energy efficiency at launch, then describes the improvement factors (non exhaustive list):

- **5G at launch**

x2

At the launch of 5G, measurements give a x2 gain factor in terms of energy efficiency compared to 4G. This x2 factor is very conservative and has been estimated for a low loaded 5G network. In later years, several other levers will improve this initial gain.

As mentioned earlier, we consider a starting point at 10% network load. In this condition, 5G energy efficiency will be around 9W / Mbps (see Fig. 2, blue curve: 750W for 80Mbps). The energy efficiency of a typical 4G network loaded at 30% is about 17W / Mbps (red curve). 5G is then 2x more efficient than 4G.

Note: 1 W/Mbps = 8/3600 kWh/GB

- **Network loading**

x2

The energy efficiency will rapidly improve by a factor of x2 due to the ramping up of traffic on our networks (see Fig. 2). Indeed, the transmitters always have a better efficiency at full charge than empty; this is particularly true for the massive MIMO transmitters used in 5G.

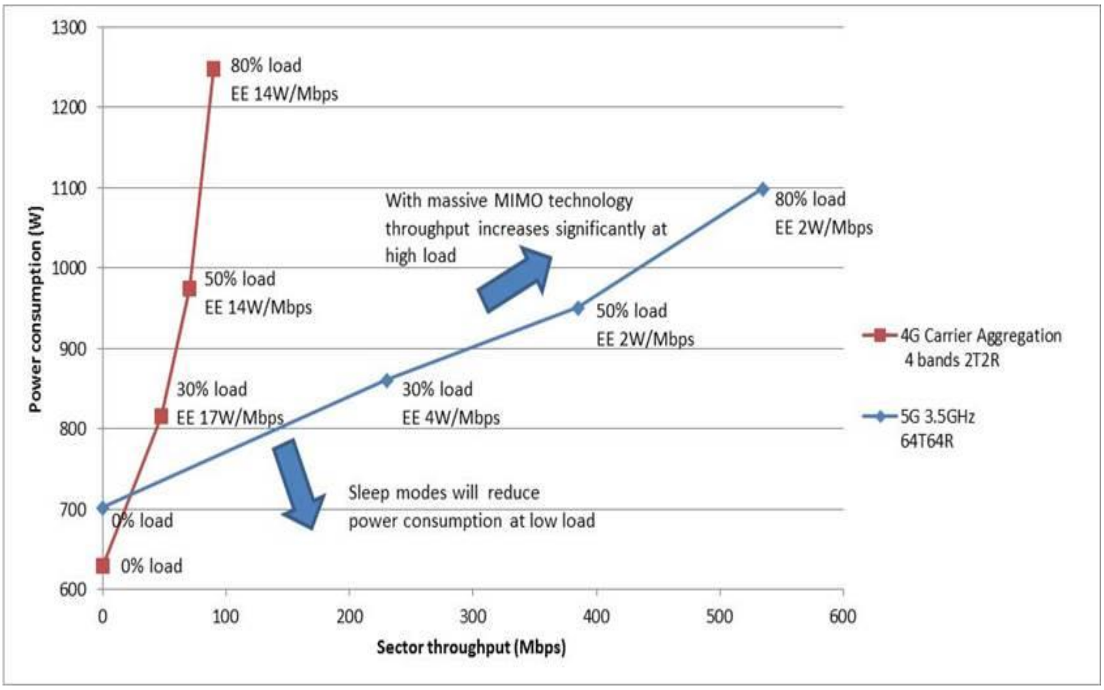

Fig. 2. 4G/5G base station efficiency

By 2025 when the 5G network will be mature (loaded at 30%), measurements give a x4 efficiency factor (4W / Mbps vs. 17W / Mbps). We shared this factor between the two levers (x2 for “5G at launch” and x2 for “Network load”).

- **Power amplifier (transmitters) efficiency**

x1.2

Power amplifiers (PA) represent 30% to 40% of 5G transmitters’ consumption. The efficiency of these PA has benefitted from advances in previous technologies. 5G transmitters are already equipped with amplifiers with efficiency rates of about 40%, which is much higher than the amplifiers of previous wireless networks at their early stage.

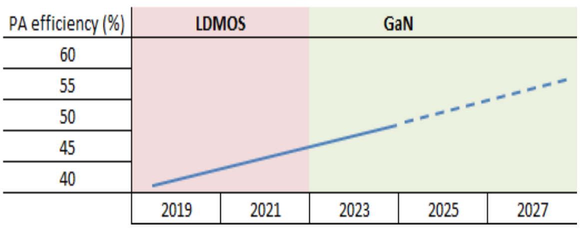

Fig. 3. PA efficiency evolution

The introduction of new technologies such as GaN (Gallium Nitride) is expected to raise efficiency to 50% in the coming years and possibly up to 60%.

- **Antenna integration**

x1.5

The 5G massive MIMO transmitters, also called active antennas, use a very recent technology which is still not completely mature. Integration is a fundamental factor with a high potential compared with passive antennas. Power amplifiers for example, which are in a separate module in passive antennas, are integrated in the radome of an active antenna. Moreover, with massive MIMO technology, a big radio frequency module was replaced by massive small amplifying chipsets integrated in the back of radiating dipoles. This caused very important integration issues between the antenna electronics (power supply, electronic tilting, phasor...) and massive amplifiers chipsets. Furthermore, massive MIMO technology imposes also the integration of a digital part inside the antenna for signal processing and beamforming management.

These components will progressively be integrated into smaller and more economical chipsets with significant room for energy efficiency improvement. This is probably the most difficult factor to estimate. The assumption of x1.5 seems very reasonable considering inputs from our industrial partnerships.

- **5G sleep modes**

x2

Sleeping, which means switching off some components, is the simplest way to reduce energy consumption. Orange has promoted and led the research and standardization of 5G sleep modes getting a consensus on the 5G new radio interface design for signaling.

Indeed, the signaling that is necessary for the initial attachment of users to the network is also the first responsible for the periodic awakening of our transmitters even if there is no traffic to serve. The lean signaling allows the implementation of much deeper and therefore more aggressive sleep modes (see Fig. 4).

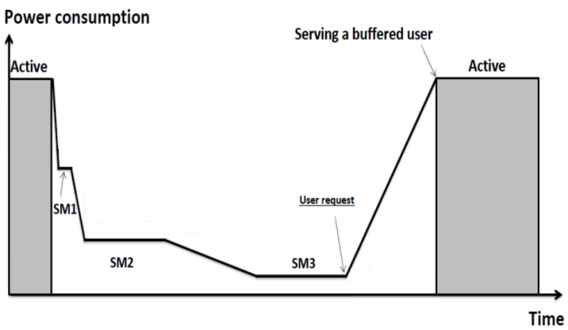

Fig. 4. 5G Advanced sleep modes

This feature is not yet completely activated because of the potential effects on latency, but the first savings are very promising even using the non-aggressive sleep modes. Thanks to artificial intelligence, Orange is promoting deeper sleeping schemes which have to be tested before deployment.

- **Signal processing (Moore's law)**

x1.1

Many improvement levers exist for enhancing the energy efficiency of the digital signal processing part of base stations. These tracks combine Moore's law (improved performance of integrated circuits) and, in longer term, the use of Cloud-RAN to pool digital radio processing between several base stations. A rough calculation gives a potential of 10% improvement in energy efficiency thanks to these advances.

- **Infrastructure sharing**

x1.3

Sharing active infrastructures (radio equipment) allows operating networks even in high traffic areas while avoiding duplicating certain equipment. This induces high OPEX/CAPEX savings, while maintaining a good quality of service.

This lever allows also reducing the energy consumption by pooling and sharing equipment in case of capacity needs. The gains depend on the geography of the countries but one can start from a distribution of 60% sites for coverage and 40% sites for capacity. In the first case, infrastructures are shared between operators (high gain). In the second case, the networks are superposed (small savings). With this hypothesis, we estimate the gain factor to be 30% after total access network sharing (savings from Orange affiliates in EU).

Note: *other gain factors have been identified, such as Multi-User-MIMO which allows to address more terminals simultaneously in case of high traffic load. These gains are unclear compared to the baseline at the launch of 5G and are applicable only occasionally. We have deliberately excluded them from this document.*

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