5G and Beyond: The power consumption challenge

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Major technical improvements are expected from 5G compared to 4G including but not only a higher throughput for the user (up to 1Gbit/s), a significant lower latency (1ms) and a dramatic power consumption reduction. As the first 5G commercial networks have been running for a few months, it appears that not all the objectives are met yet, especially in terms of power consumption.

THE 5G OBJECTIVES

When the standardization work was initiated at the 3GPP, the objectives were very ambitious (see Fig 1). The key ones were:

- 1 Gbit/s on the user side, with a peak data rate of 20 Gbit/s and a traffic density of 10 Tbit/s/km^2,
- 1ms or better as a latency time,
- A high device density of 200,000/Km^2,
- A significant power reduction, leading for instance to an average device battery lifetime of 15 years.

Note that the low latency requirement applies mainly for specific URLLC (Ultra-Reliable-Low-Latency-Communication) applications, when the low power consumption is a generic objective.

For the air interface 3GPP made the decision to go for an OFDM modulation as it is already used in 4G but with a lot more flexibility in the structure of the signal as an improved and more versatile numerology would help reaching the objectives. A complementary decision was made to introduce massive-MIMO [1] technology. All those points are intended to help the operators transitioning from 4G to 5G.

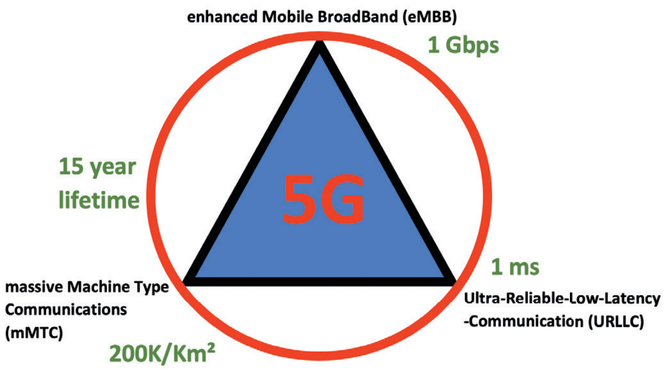

Figure 1: 5G Key Objectives

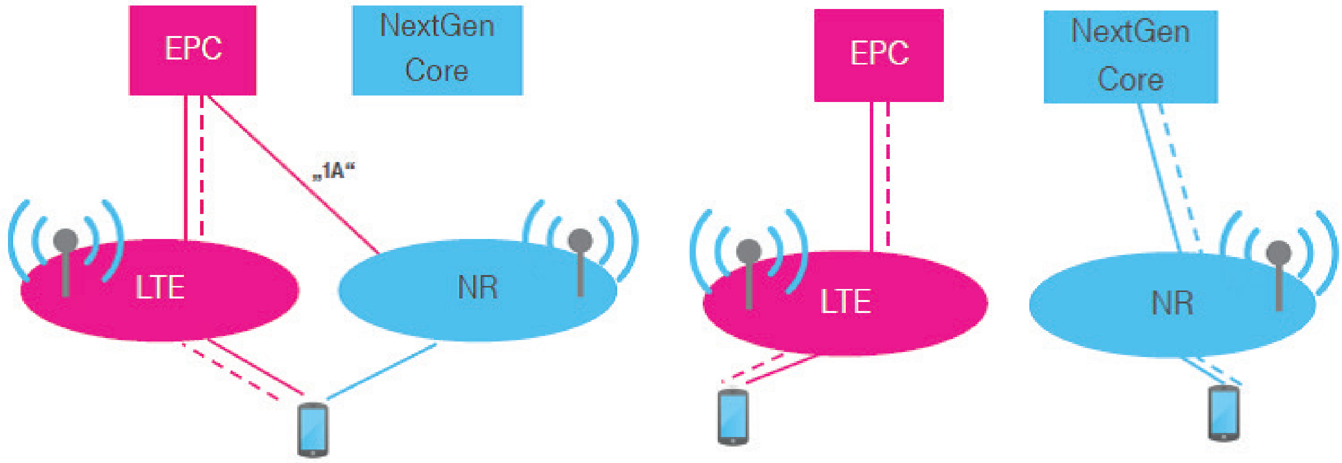

Figure 2: Network architecture NSA (Non Stand-Alone) [left] vs SA (Stand-Alone) [right]

THE ACHIEVEMENTS

The first 5G networks have been launched in 2019 in several countries over the world (Korea, Australia, the UK, Switzerland, …). At this point the operators are all carefully transitioning from their 4G network architecture to a pure 5G network with what is so-called a Non-Stand-Alone (NSA) architecture that will progressively migrate to a Stand-Alone (SA) architecture (see Fig 2).

Even if all the 5G objectives cannot be reached in an NSA network due to the 4G network limitations, especially the latency time, recent field tests demonstrate that in a SA network the latency time and the throughput will be technically achievable or close to be achievable.

One point is lagging behind: the power consumption. At this point it is estimated that a 5G network consumes about 3 times more power than a 4G network, when at least a 10-fold reduction was expected. This disappointing achievement cannot be explained by a single reason; it is instead a combination of technological and theoretical blocking points, mainly:

- The energy storage battery efficiency is improving too slowly,
- Massive-MIMO antenna technology was supposed to allow a significant reduction of the power consumption. But the fact is that the signal processing of a massive-MIMO active antenna can represent up to 40% of the total power consumption of a below-6GHz active antenna, and may be even larger in mm-Wave active antennas.

This more-than-expected power consumption leads to a noticeable increased OpEx for the operators and ultimately an increased subscription cost which may slow down the widespread deployment of 5G.

In the case of massive-MIMO antennas in mm-Wave frequency, technologies are available that could improve the overall power consumption, for instance antennas based on Liquid Crystal (LC) technologies (read inserted text below), especially as their performance gets better when frequency increases, but even more is needed, especially on the signal processing side, if the 6G is kept in perspective.

The 6G will target a peak data rate of 1Tbit/s, a 40dB better link budget and a connection density of 10 devices/m^2 that can only be achieved if something new in telecommunication theory emerges. All telecommunication equipment, even the most recent ones, are based on technologies originated in the 50's and 60's, such as the Shannon's and Moore's laws. The technology that could lead to the necessary power efficiency improvement on the signal processing side is still to be invented.

CONCLUSION

As the first 5G networks are rolling out, it appears that most of the initial objectives are met or close to be met. Only one is definitely not met: the power consumption reduction. Huge theoretical and technological efforts will be needed to go beyond the current status and to make the coming 6G a success.

LC (Liquid Crystal) technology is one of the technologies that could be a first step to bridge the gap, especially for mm-Wave active antennas.

Liquide Crystal (LC) is a tuneable material which enables agile antenna solutions, e.g. phased arrays [2]. LC based phased array antennas combine the LC tunability and phased array topology. Similar to LC Displays (LCDs), phase shifters can be arranged as pixels, i.e. a phase shifter per radiating element of the array. As an example, Fig. 3 shows an well-known LC phase shifter in microstrip line topology. By applying a proper voltage between the microstrip line and its ground, the LC molecules reorient according to the magnitude of the applied voltage. This reorientation results in change of effective permittivity and therefore phase shift within the microstrip line. Other topologies are possible, and ALCAN has developed its own patented topologies with optimized performances.

The technology is entirely passive, biasing requires very low power and ALCAN has its own patented low-cost electronics solution, developed exclusively for phased arrays. In this solution, controlling up to 512 radiating elements will consume a power of less than **half a watt**, which represents an 30x improvement over standard semiconductor based phases shifters.

By leveraging the existing mass production capabilities of LC Display production lines, as well as the low marginal cost of producing additional types of LC panel, ALCAN is able to reduce the LC phase shifter costs by 100× to around \$300/m² compared to semiconductor-based phase shifter costs, which are estimated to be around \$30,000/m² when using 30cm diameter wafers.

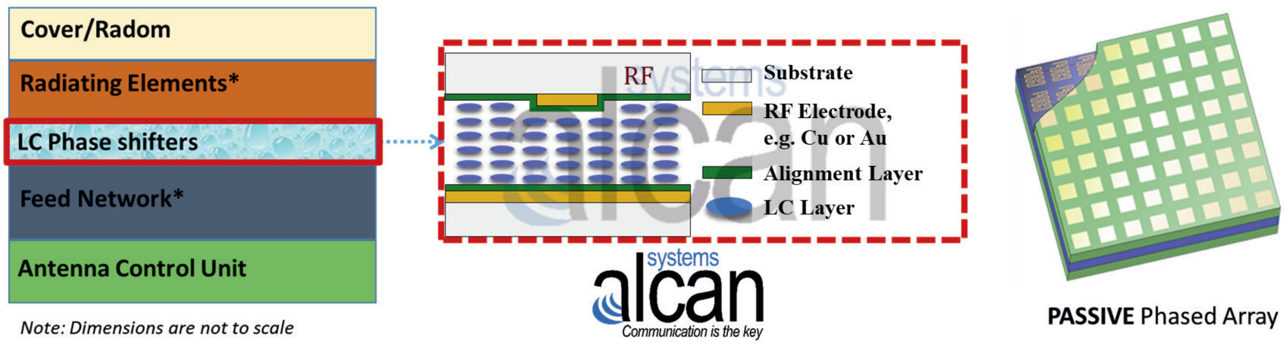

Figure 3: **ALCAN LC based phased array with detailed stack layout**

REFERENCES

[1] "Non-cooperative Cellular Wireless with Unlimited Numbers of Base Station Antennas" Thomas L. Marzetta, IEEE Transactions on Wireless Communications (Volume: 9, Issue: 11, November 2010)

[2] „Microwave Liquid Crystal Technology“ H. Maune M. Jost R. Reese E. Polat M. Nickel R. Jakoby Crystals (Volum:8, Issue: 9, 2018, pp. 355)

ABOUT AUTHORS

Andrè Doll is the previous Chief Technology Officer for Radio Frequency Systems (RFS), a subsidiary of Nokia, until his recent retirement. He is currently consulting as 5G antenna expert.

André has more than 30 years of experience in wireless network technologies and was an active member of 5G standardization bodies (3GPP, ETSI, NGMN). André is an innovator and contributed with his team to generate many patents for RFS.

Prior to his role of CTO, André hold several senior positions in product management and R&D. André started his international career with Hewlett Packard in the Silicon Valley. Throughout his career, he played a key role in several technology breakthroughs, such as the first use of optical fiber for submarine transatlantic transmission lines.

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