WHITE PAPER

Radio Access Network energy efficiency

NOKIA

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1. Introduction

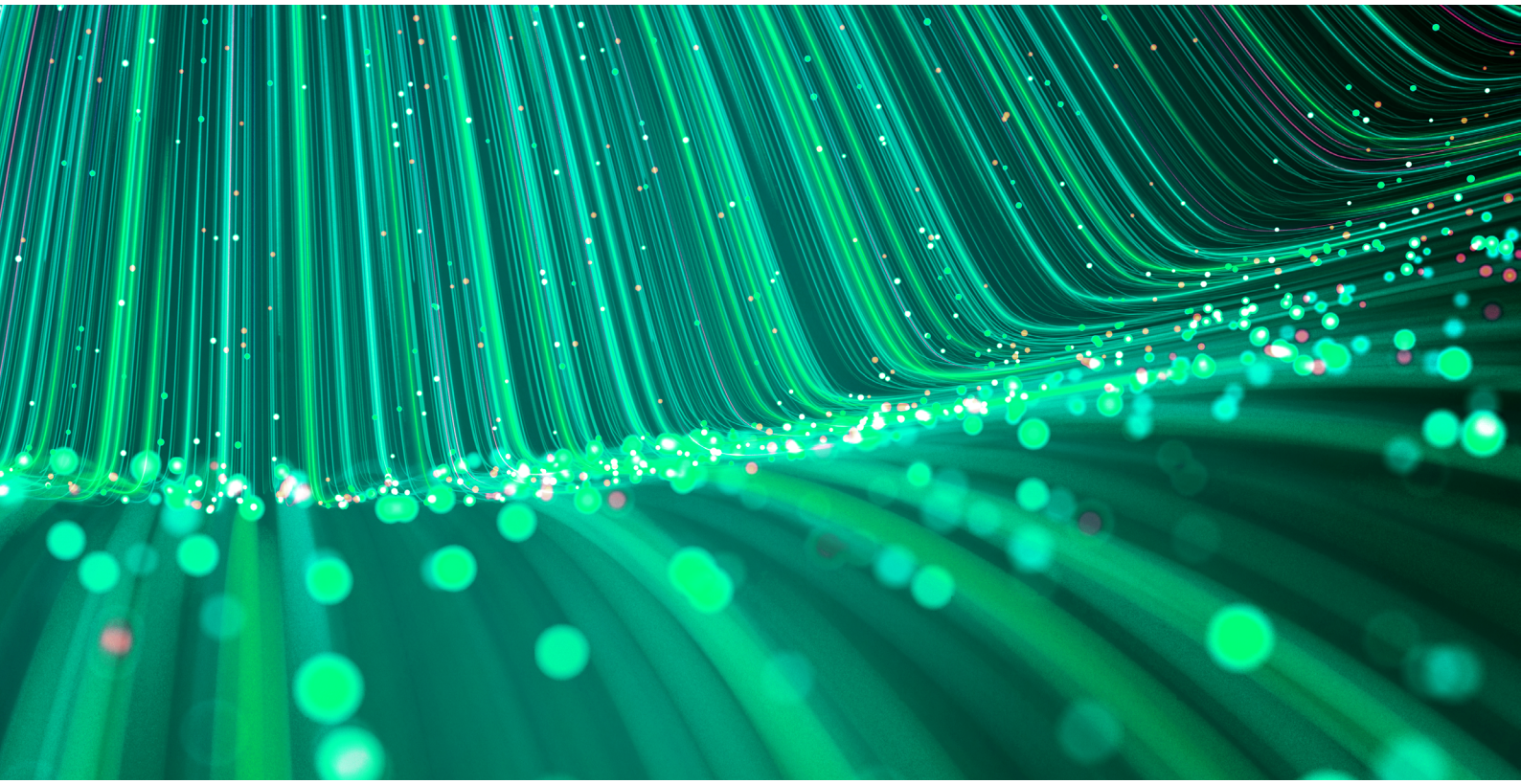
Improving energy efficiency is good for the environment. It also makes commercial sense for communications service providers (CSPs) to support sustainable, profitable business as energy prices and capacity demand continue to soar.

Energy Efficiency is also a focus of political and regulatory authorities, which are increasingly mandating improvements in sustainability and energy consumption for all industries, including CSPs.

As a strategic mobile network supplier, Nokia acknowledges its role and responsibility to provide solutions and support our CSP customers to continuously pursue these goals.

Industry papers from organizations such as GSMA[1] and NGMN[2] report on studies showing that the RAN consumes approximately 75 percent of the energy used in a CSP's network, whereas the remaining 25 percent is consumed by Core, Data Centers and Operations. Broken down further, 60-70 percent of the RAN consumption is attributable to base station equipment, and 80 percent of that is consumed by the radio units with the remaining 20 percent for the baseband portion. Nokia is focusing and accelerating its energy-efficiency solutions based on measures aimed at achieving maximum positive impact.

In this white paper, we focus on the software, hardware, and services that reduce the energy consumption of radio access networks.



2. Innovative technologies to drive towards zero traffic, zero energy

Radio unit technology innovations

The radio units (RU) consume approximately 80 percent of the overall base station power consumption. In an optimal solution, the RU exhibits a linear power consumption versus the traffic load, consuming as close as possible to zero Watts when there is no traffic. To achieve this, the performance efficiency of each RU function, along with an RU architecture that allows turning off a maximum number of components, is important.

In the latest Massive MIMO radio units, Nokia has enhanced the efficiency of the following aspects compared to the characteristics of existing product generations:

Power amplifiers in Nokia RF units utilize the most energy-efficient RF device technology based on gallium nitride (GaN) material, which maximizes the power density and efficiency of the units. An optimized architecture according to each product variant enables reaching over 50 percent efficiency in the PA device final stage level.

Nokia AirScale Habrok Massive MIMO units launched in 2023 utilize the latest generation of our ReefShark System-on-Chip (SoC). This latest generation SoC improves energy efficiency in multiple ways.

For the same power consumption, our latest SoC generation can process about eight times more data than the existing generation. This lowers the energy consumption for algorithms of the same complexity. In addition, it allows the implementation of even more powerful mechanisms to control power amplifiers, which helps deliver optimum performance at a wider range of conditions.

With improved scalability, the platform enables a wider range of products with different capacity levels. In the upcoming products, we can better tailor the needed capacity to the different units which results in a more optimized implementation for energy efficiency.

The latest generation SoC used in Habrok inherently adapts the internal resources to the actual processing needs, thus optimizing power consumption according to traffic load. It particularly improves the performance at lower traffic loads, which is a typical scenario in the first stages of 5G deployments.

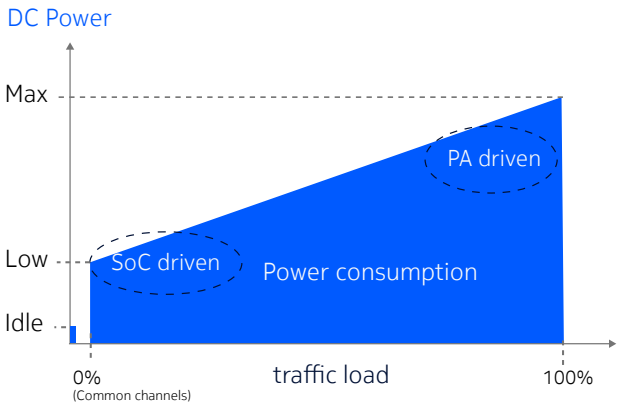


Figure 1. Key radio unit contributors for radio unit power consumption

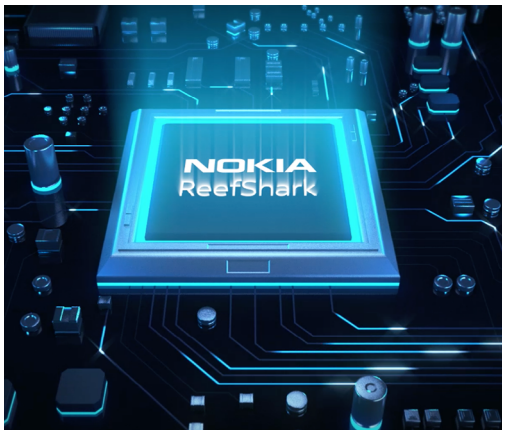
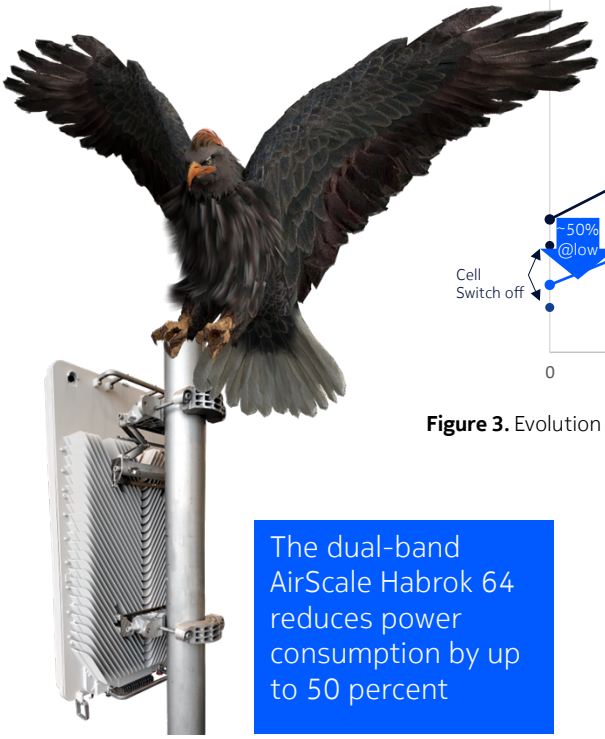


Figure 2. Energy-efficient ReefShark System-on-Chip

In Nokia AirScale Habrok 64, the power consumption across traffic load is reduced by almost 40 percent compared to AirScale Osprey 64. In an idle state, it is enhanced by up to 50 percent.



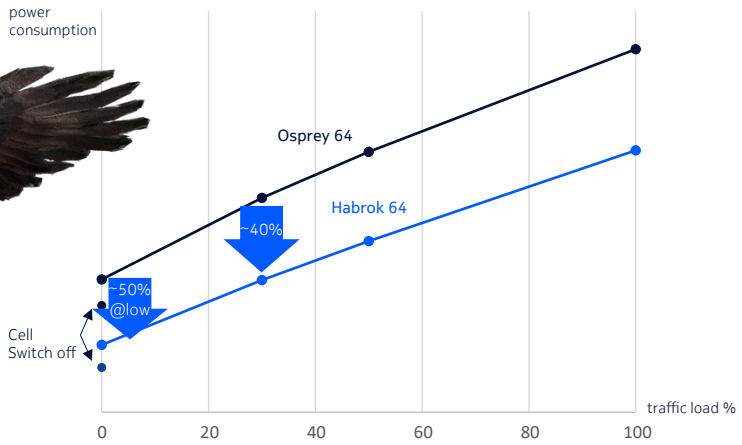


Figure 3. Evolution in power consumption between Massive MIMO radio generations

The dual-band AirScale Habrok 64 reduces power consumption by up to 50 percent

For AirScale Pandion triple-band remote radio head (RRH) for 700/800/900 MHz, the power consumption is reduced by approximately 30 percent across the traffic load compared to the existing generation of the product.

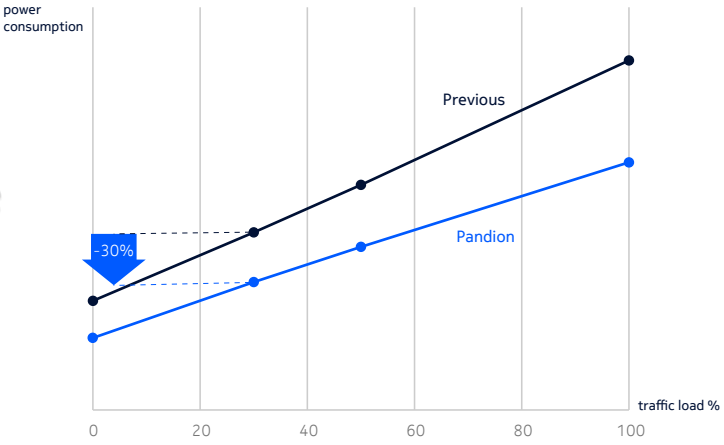


Figure 4. Evolution in power consumption between triple-band RRH radio generations

Baseband technology innovations

The key enabler for higher baseband energy efficiency is optimized processing with new Nokia silicon technology and adaptive power savings. The latest generation of Nokia ReefShark System-on-Chip (SoC) enables twice the performance with half the power consumption.

The latest AirScale baseband units provide:

• The latest silicon node process, which reduces power draw.

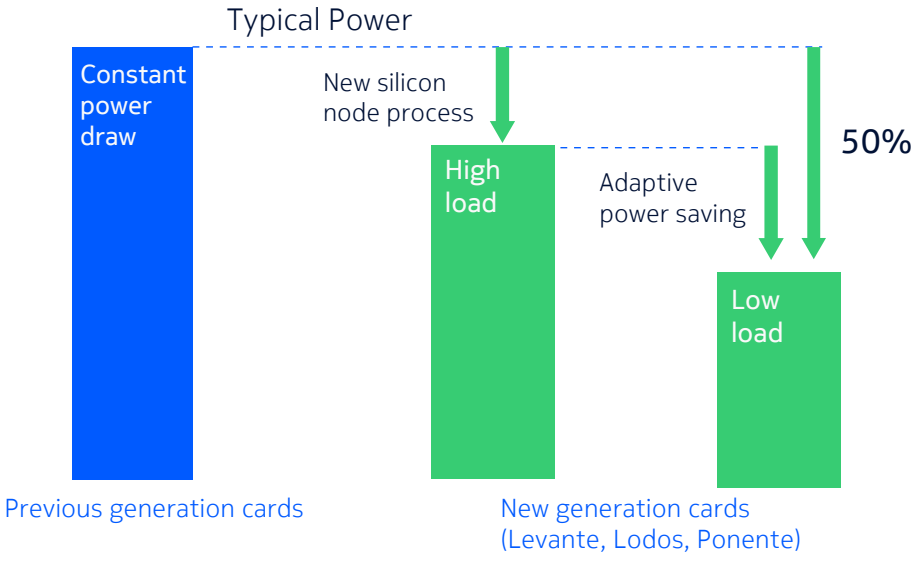
• An adaptive power-saving capability, which means that unused CPU and hardware resources enter the idle mode autonomously.

• Market-leading energy efficiency, delivering up to 135 Mbps/Watt.

Our ultra-performance baseband capacity card, Levante, doubles the number of supported Massive MIMO cells and yet reduces energy consumption by up to 60 percent. The high-performance variant, Lodos, reduces energy consumption by up to 30 percent.

The ultra-performance baseband control card, Ponente, supports increased traffic growth with up to 100 percent higher throughput capacity with up to 80 percent lower energy consumption.

For outdoor deployments, we have the compact, zero-footprint Tuuli 6 and Tuuli 12 baseband products.



Low load: Based on ETSI ES 202 706-1, for 24R1 SW release and typical configuration and including fronthaul SFPs. Value at 25°C ambient temperature.

High load: "high UE load in connected cells, high number of supported cells per BB card in use" All baseband processing resources active under high load of the unit, in 24R1 SW release. Value at 25°C ambient temperature

Figure 5. Evolution in power consumption between baseband generations

Energy-saving site solutions

Traditional shelter deployments require a lot of space, raw material and need active cooling to regulate the temperature, which results in high energy consumption. According to a recent NGMN White Paper, the power consumption of the site auxiliaries can be more than one third of the total site energy consumption.

Nokia has developed a portfolio of innovative site solutions, which can reduce the average energy consumption of radio sites by up to 30 percent. Our site solutions also support renewable (solar) energy, which helps achieve additional OPEX savings and reduce carbon emissions.

Nokia All-in-one cabinet solution eliminates the need for traditional indoor shelters, significantly reducing the site footprint and providing a compact alternative for space-constrained environments. It significantly decreases the energy consumption of the site because efficient heat exchangers are used instead of inefficient active air cooling.

Nokia Zero footprint site solution offers the highest energy efficiency:

- All equipment is mounted on a tower, pole or wall.
- No active cooling is used for the power equipment or batteries.
- The AC power is brought closer to the point of consumption, reducing energy loss in DC cables, which is often at the level of 5-15 percent.
- Scalable site configuration, no wasted energy in over-dimensioned hardware.
- Advanced rectifiers with higher energy efficiency compared to existing product generations.
- Intelligent power distribution units that leverage e-fuse technology for shutting down the DC feed of the equipment that is not in active use.

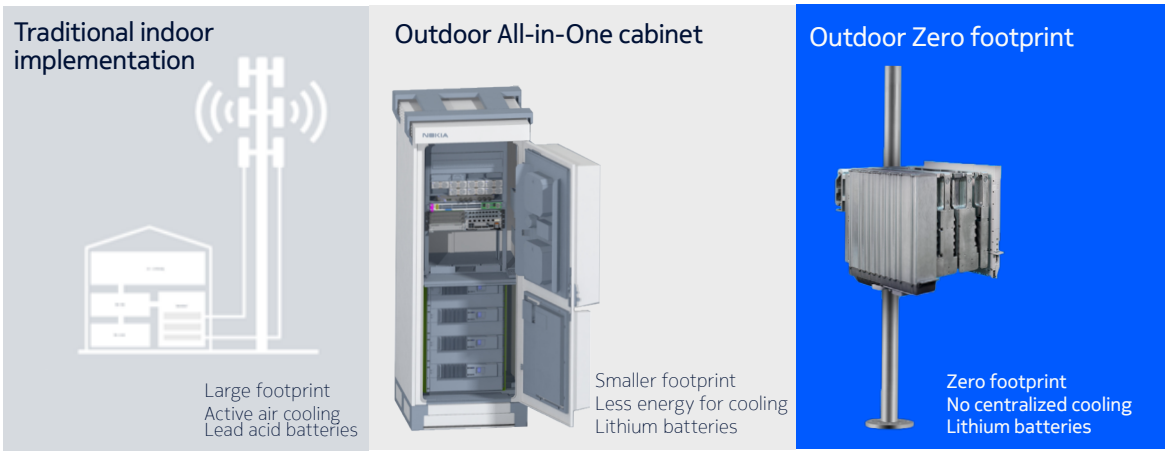


Figure 6. Traditional indoor site compared to outdoor All-in-One cabinet and Zero-footprint site solution

Liquid-cooled AirScale baseband hotels

Almost all of the energy consumed by baseband is converted to waste heat. Traditional site cooling systems depend on active air-cooling, which is very inefficient. When using active air-cooling equipment, the cooling system's share of the total energy consumption of a base station site can exceed 30 percent

Nokia's unique Liquid Cooling solution can reduce the cooling system energy consumption by up to 90 percent. A particularly suitable use case for liquid-cooled baseband is a centralized Baseband Hotel, which combines many baseband units into central locations, and hence has a very high heat load. Using a cold plate adjacent to hot components, liquids directly carry away the heat load from the site.

Using a cold plate adjacent to hot components, the liquid can directly carry away the heat load from the site and enable stable cooling for all baseband units. Liquids can capture up to 80 percent of the waste heat and this brings an opportunity to circulate the captured heat for other purposes, such as building heating, enabling up to 80 percent reduction in baseband carbon dioxide emissions.

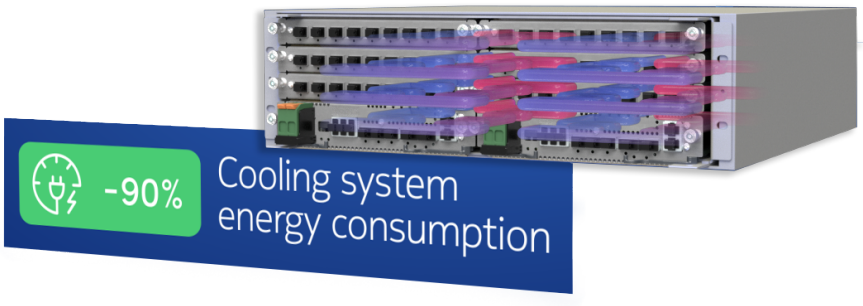


Figure 7. Liquid Cooling reduces baseband energy consumption by up to 90%

Figure 8. Liquid-cooled AirScale baseband solution

3. RAN Software capabilities to reduce RAN power consumption

Beyond hardware, key techniques to enhance RAN energy efficiency include adaptations of radio network parameters in time, frequency, spatial and power domains in response to traffic variations. These adaptive capabilities play a pivotal role in optimizing power consumption while maintaining network performance and coverage, whatever the traffic load.

Boosting coverage and capacity per Watt

One of the main learnings from 5G rollouts so far has been that Beamforming antennas have delivered on the industry's ambition of re-using existing sites and improving spectral efficiency. Beamforming makes better use of the transmitted energy by focusing the signal on the direction where the terminal of interest is located. This translates into better system performance in terms of coverage, data rates, energy efficiency and capacity per cell for 5G Massive MIMO. Nokia has the capability to apply the beamforming gains both in user and control plane channels to maximize the overall system benefits.

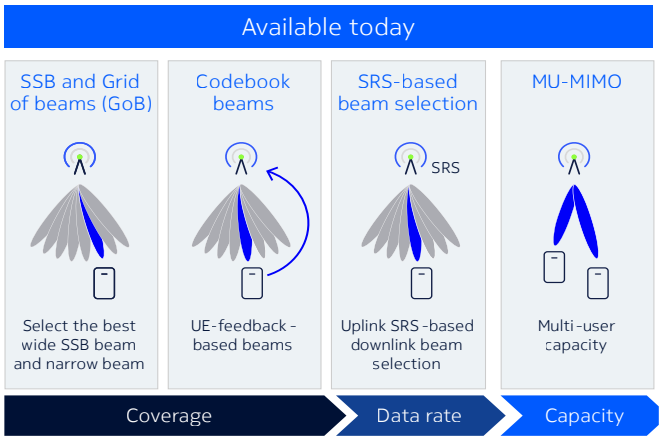


Figure 9. Evolution steps of Nokia beamforming algorithms

Achieving better coverage and capacity with the same emitted power means that we can deliver the same network performance with fewer sites, significantly decreasing the Watt/Gigabyte ratio. This important fact is often not considered in CSP benchmarking. Interestingly, a recent benchmarking showed that a competitor had to significantly boost output power to match their base station site's coverage area with Nokia's solution. That caused the power consumption in the competitor's network to rise steeply.

Nokia provides Smart Synchronization Signal Block (SSB)-based Beamforming, which can increase the coverage by 6-9 dB compared to the Sector SSB approach, in which just a single SSB is used. This helps CSPs decrease the overall energy consumption at the network level. Increasing the data rates within a given spectrum window with the same emitted power also significantly decreases the Watt/Gigabyte ratio.

The generalization of Multi-User MIMO algorithms further improves the capacity in the networks when the network load is increasing. Nokia already provides multiple Beamforming schemes for capacity enhancements, and we have more features on the roadmap especially for further enhancement of MU-MIMO performance.

Energy-saving RAN software features

Energy-saving RAN software features are designed to mute resources when they are not needed. For example, during the daytime, we can mute power amplifiers when there is no data to transmit. At night time, we can mute MIMO and Massive MIMO transmitters, switch off cells to deem sleep and extreme deep sleep modes or even switch off the whole radio unit when there is no mobile traffic

The highest potential for RAN energy savings is minimizing power consumption at times of low traffic.

The already available Nokia software features for low/medium traffic conditions include:

• Enhanced µDTX (micro DTX, Discontinuous Transmission) function, which can switch off power amplifiers at an interval of a microsecond when there is no data to transmit.

• MIMO and Massive MIMO muting, which can de-activate half of the transceivers when traffic load goes below a set threshold.

For very low traffic conditions, the available Nokia software algorithms include:

• Cell shut-down mechanism, which turns off individual unused cells.

• Deep Sleep mode, which reduces power consumption further but enables fast recovery when the traffic volume increases. Recent competitive benchmarking in a live customer network in France confirms that Nokia Massive MIMO Deep Sleep capability outperforms competition, resulting in superior energy efficiency over a 24-hour period.

• Extreme Deep Sleep mode introduced in the latest AirScale Habrok Massive MIMO variants. This will bring power consumption down to a level of <20W. Feedback from a leading pan-European CSP and from a leading CSP in India is that Nokia's Extreme Deep Sleep mode outperforms the competition.

The figure below shows the incremental impact of energy-saving software features.

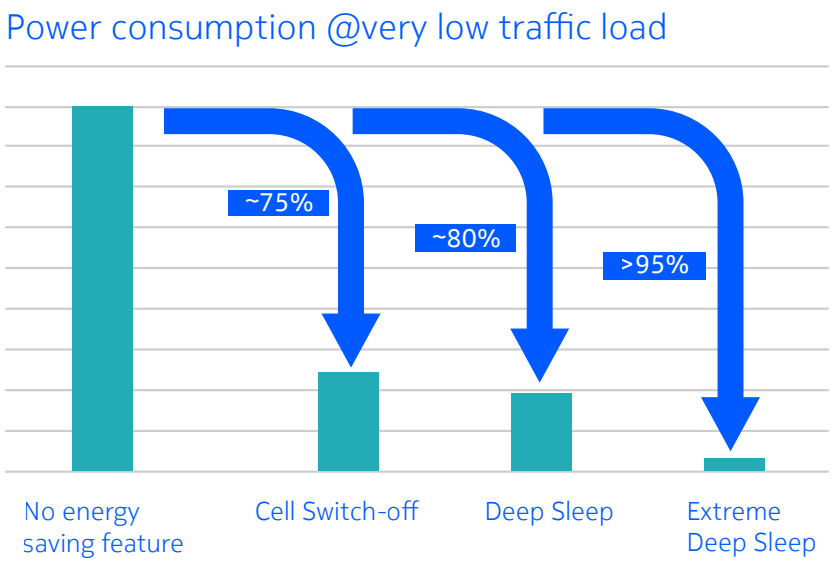


Figure 10. Energy efficiency software features driving towards zero traffic zero energy

Nokia commits to continue enriching its RAN software efficiency roadmap in 2024 and beyond.

End-user device energy efficiency features

The power consumption of end-user mobile devices plays a major role in the overall power consumption of the mobile network. It also impacts the battery lifetime of a smartphone, which consequently has an impact on both sustainability and end-user satisfaction. Some 5G smartphone models can consume up to 1.8 times more energy per connection compared to 4G connections while obtaining four times higher data rates.

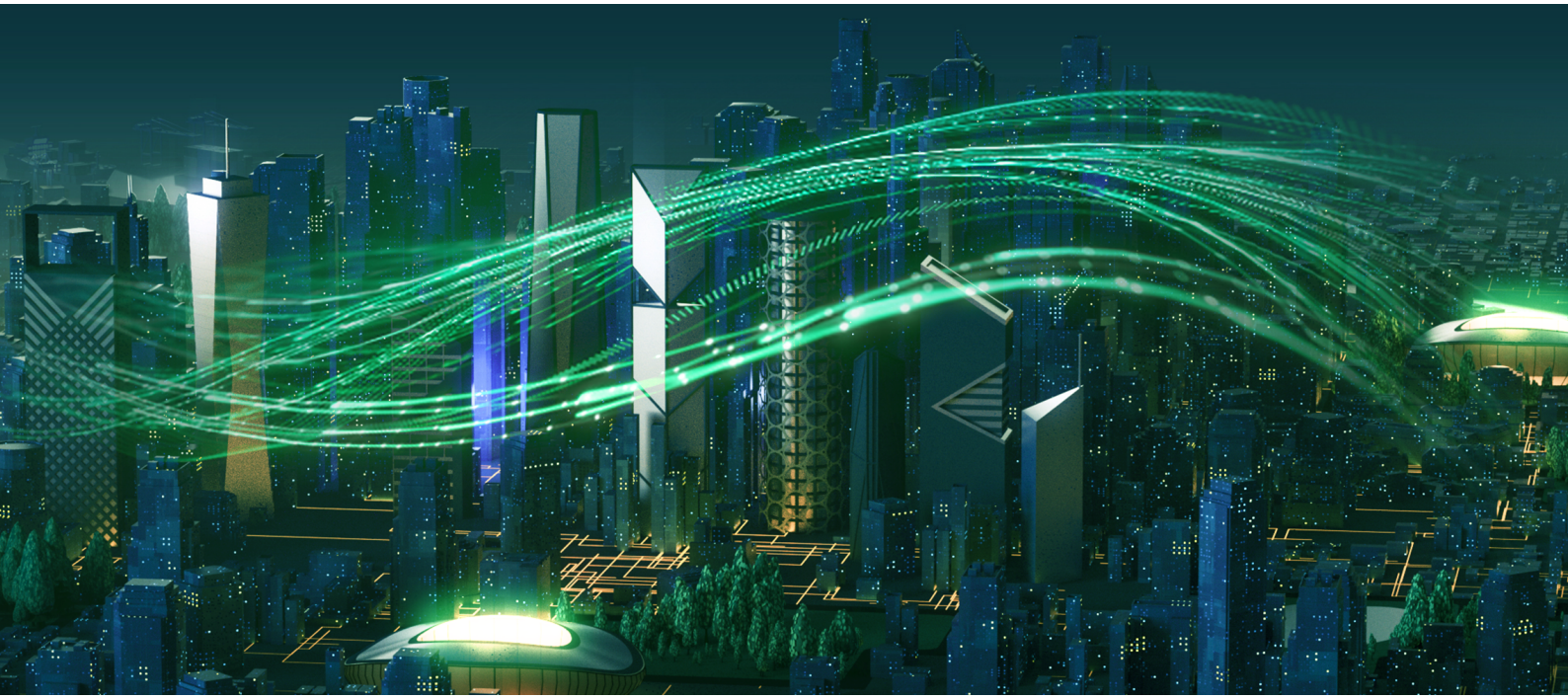
Based on UE power consumption studies, the following points have been identified:

• The largest contributor to (unnecessary) power consumption in the modem is typically the Physical Downlink Control Channel (PDCCH) monitoring.

• In the RRC Idle / Inactive state, in which the UE spends most of the time, the UE benefits from infrequent paging or PDCCH monitoring, and can thus sleep most of the time.

• In the RRC Connected state, the UE typically monitors PDCCH more frequently, and can hence sleep (much) less.

Nokia's roadmap for network-assisted UE power-saving features takes all these aspects into consideration.



4. AI/ML-powered energy-savings management and monitoring

MantaRay SON energy savings management

The energy savings management capabilities of Nokia MantaRay SON, the Self-Organizing Networks solution, automate the configuration of energy-saving software features while ensuring that the energy optimizations performed with AI/ML have no impact on throughput and other key KPIs. MantaRay SON can optimize energy savings in multi-vendor RAN environments.

The AI/ML-powered features of Nokia MantaRay SON to boost energy efficiency include:

- Traffic load aware energy efficiency optimizations to extend energy-saving time periods result in up to 10 percent additional energy savings.
- Inter-BTS and inter-technology coordination for energy efficiency, resulting in up to 10 percent more energy savings.
- Deep sleep support for timely energy savings with no impact on the quality of service
- Traffic threshold optimization for energy efficiency provides additional energy savings while maintaining user-level Quality of Service (QoS).

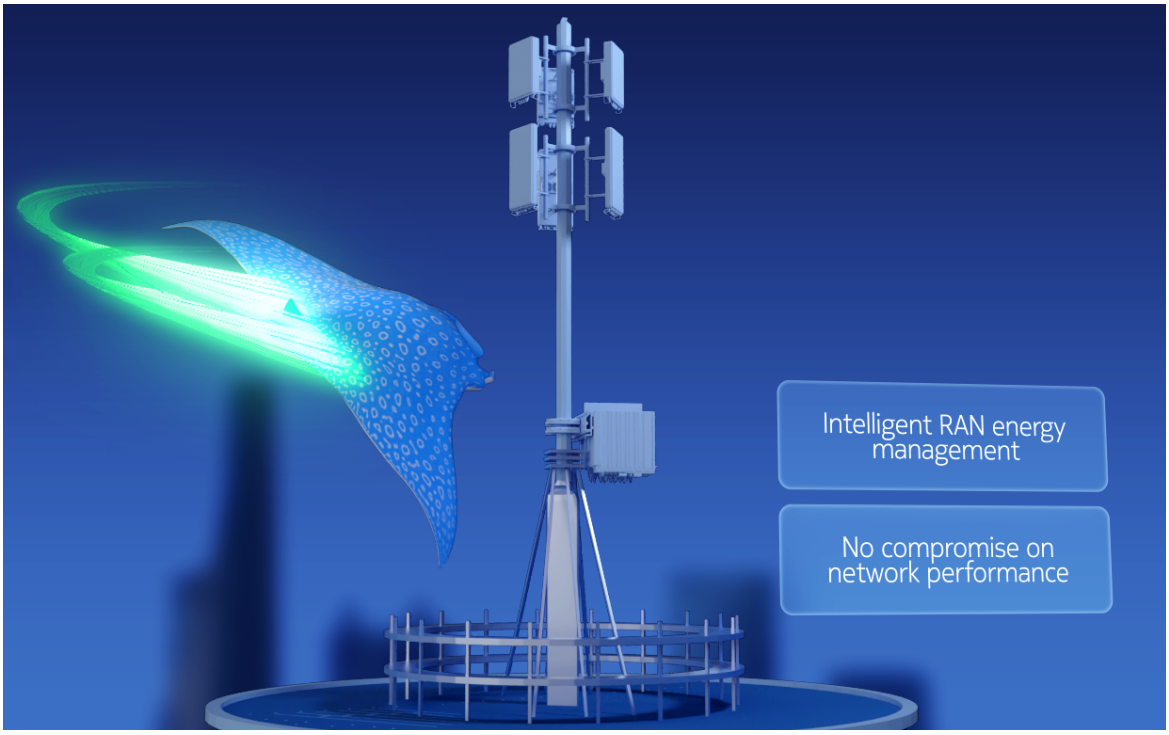


Figure 11. MantaRay SON AI/ML-powered energy savings management

MantaRay NM reporting capability for energy analytics

Multiple operators are currently building energy management systems, which include energy metering from the network but also other elements such as real-time price of energy, associated decision rules for dual source site energy feeding or overall energy dashboards.

Nokia MantaRay NM provides a rich set of reports and KPIs, including energy efficiency related metrics. It also supports the creation of custom reports. The MantaRay NM supports both top-down monitoring at the network and region level and drill-down capabilities at the site level.

The pre-defined automated reports and KPIs include:

- **Cell power saving mode ratio (%):** indicates which percentage of the cells are operating in power-saving mode.
- **Energy efficiency KPI (kWh/GB):** identifies sites with high energy consumption during low traffic situations, indicating an anomaly.
- **BTS power consumption:** provided for SBTS, System Module level and Radio Module level.
- **Sleeping cell report:** monitors cells not carrying traffic, but consuming energy.

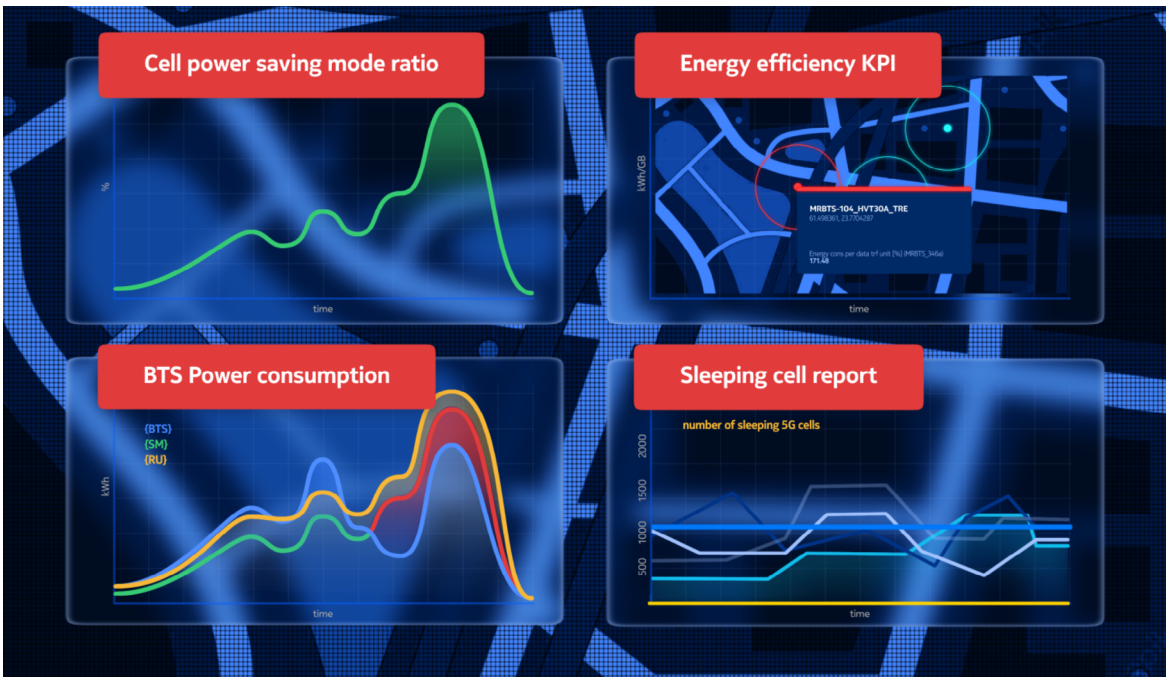


Figure 12. MantaRay NM energy savings dashboard

Optionally, the sites can be plotted in a Geographic Information System (GIS) map to give a visual heatmap of energy-related KPIs. This helps correlate the energy consumption patterns to site-specific activities, deployment of Nokia RAN energy-saving features, and usage of modernized hardware.

Additionally, MantaRay NM can configure rules to trigger alarms in case certain key energy-related KPIs deviate from the acceptable threshold. This supports proactive actions before the KPI goes to an unacceptable level.

The performance metrics can be analyzed not only for Nokia RAN, but also for any SNMP device integrated to MantaRay NM. Such performance metrics that monitor energy efficiency can be forwarded in 3GPP standardized format so that any upstream analytics application can further process the data if needed.

Virtual Power Plant

Virtual power plant (VPP) is an innovative solution that helps support power grid stability by ensuring the supply and demand are in balance. Power grid balance can be restored by either reducing demand through switching AC consumption off and by using available reserves, or by increasing supply.

Nokia's Virtual Power Plant solution utilizes existing base station power systems and batteries. It enables CSPs to offer their backup battery assets as reserves to Transmission System Operators (TSO) that are maintaining a marketplace for frequency balancing trading. This unlocks an opportunity for operators to generate additional revenue and help reduce carbon emissions by taking intelligently into use the energy in the existing backup batteries even when there is no failure in the power grid system.

A typical VPP scenario is where the CSP and the TSO agree that base stations are run by using the reserve batteries to balance the grid frequency. In practice, this is needed only for short periods of time, and the TSO will financially compensate this to the CSP.

Nokia's VPP controller also facilitates load shifting, as it gives the CSP a centralized control mechanism for moving to battery usage when energy prices are high. Batteries are then recharged during periods of low energy prices. This requires no interaction with a TSO or an energy company.

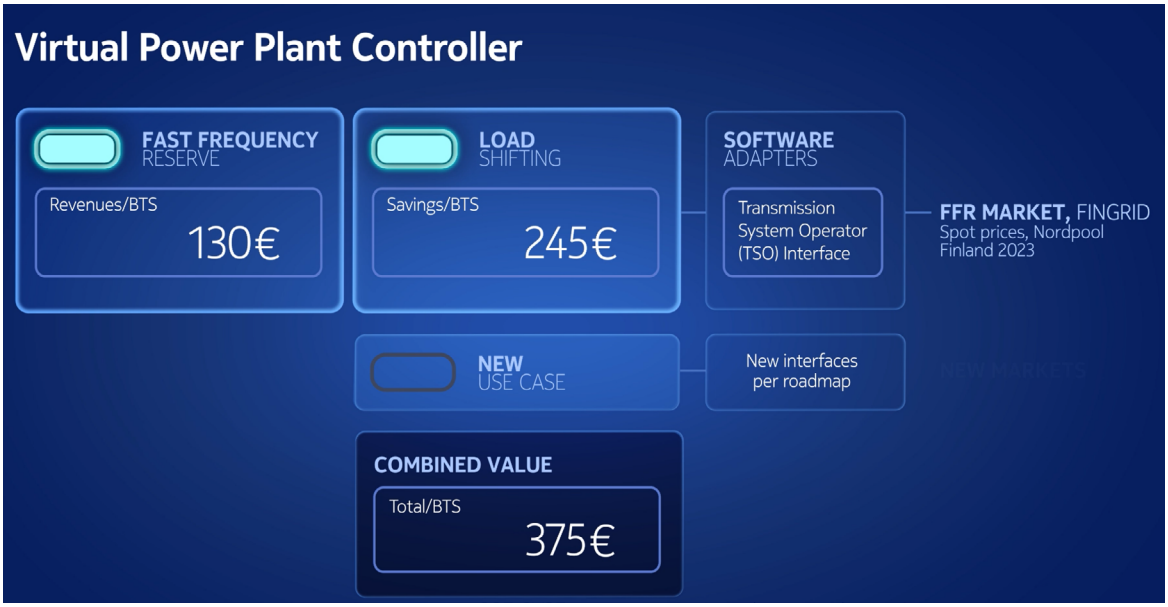


Figure 13. Nokia's Virtual Power Plant solution concept

5. Network design services to further improve energy efficiency

Building on top of the in-built energy-saving features of Nokia products, the Network design services ensure the best customer-defined balance between performance and energy efficiency.

Customized power settings with digital design

Nokia's Digital Design approach for enhancing energy efficiency considers each individual cell in the network with respect to interference, load, and antenna configuration, the percentage of physical resource block (PRB) utilization, the inter-site distance, and the environment. The result is a cell-based optimized configuration with overall lower transmit power compared to using the same power setting on all cells of a network layer, spectrum band or carrier. The advanced analytics guarantee that there is no performance degradation.

This approach has been tested in mobile networks around the world, including all types of network topologies, a variety of spectrum frequency bands and bandwidths, with both Massive MIMO and non Massive MIMO equipment for 4G and 5G configurations. The experience over multiple projects shows, on average, a 15 percent reduction in energy consumption while maintaining high network performance.

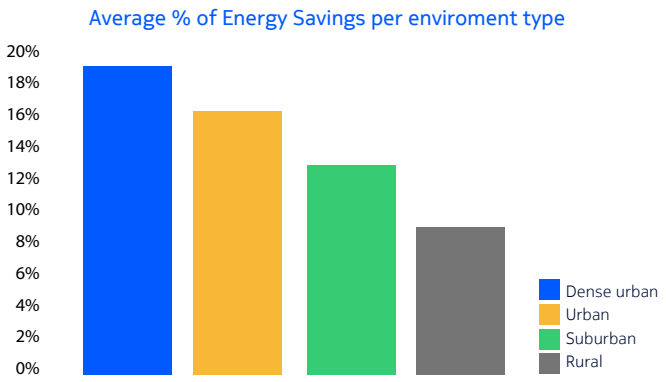


Figure 14. Power reduction distribution and Energy savings

15%

Reduction in power consumption

17%

Improvement in downlink throughput performance

Enhancing performance hand-in-hand with energy efficiency

Nokia Design Engine analyzes customer networks in an automated process. Based on various data sources, it provides accurate identification of the cells that can be optimized for performance and energy efficiency by the reduction of PRB utilization. This can bring up to 20 percent energy savings at busy hours.

Nokia provides full 3D optimization of the beam sets, which helps enhance Massive MIMO energy efficiency while also enhancing radio performance. In trials with customers across 10 cities, we observed a 17 percent downlink throughput performance improvement with 3D optimization.

6. Industry-leading Cloud RAN energy efficiency

Nokia 5G Cloud RAN is built on the Nokia anyRAN approach that ensures feature and performance consistency between purpose-built RAN, hybrid networks and Cloud RAN with common software and In-Line architecture for L1 acceleration.

Thanks to the Nokia anyRAN approach, the Cloud RAN solution comes with native feature parity for energy-saving optimizations. This approach gives Nokia a best-in-class position for energy efficiency when considering the overall solution power consumption.

For the baseband part of a Cloud RAN solution – the part that is not radio units – the power consumption and comparison with purpose-built design is very much dependent on server-level capacities and on the Cloud RAN deployment model. Typical factors include the location of the virtualized distributed unit (vDU) and virtualized centralized unit (vCU) functions, and the extent to which they may benefit from centralization and resource pooling with a scalable design.

The following figure gives indicative power consumption for the main types of Cloud RAN deployments. This provides an indication to which extent the centralized vCU/vDU improves the energy efficiency of the Cloud RAN deployment.

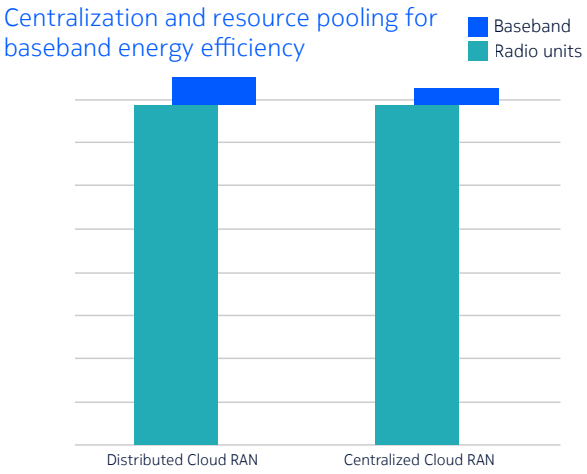


Figure 15. Comparison of distributed Cloud RAN and centralized Cloud RAN

The Nokia anyRAN approach brings the following energy-efficiency benefits:

- vDU scalability with L1 on SoC allows adapting the configuration and footprint according to traffic load thanks to independent pooling of general-purpose processors for higher layer processing and In-Line accelerators for L1.
- L2/L3 deployment versatility with the flexibility to choose energy-optimized ARM and AMD processors as an alternative to the x86 option. It also opens the door for innovations from new companies entering the processor market.
- Optimized cloud-native software with high performance and energy efficiency at the heart of design for deployments on partners' cloud infrastructures.

7. Conclusion

At Nokia, we have a strong commitment to our Environmental, Social, and Governance (ESG) responsibilities. We are proud of the constant advances we have achieved in enhancing the energy efficiency of our products and what we know is possible to accomplish in the future.

Improving the energy efficiency of mobile networks requires pulling all possible levers, and Nokia is certainly doing that.

Our ReefShark System-on-Chips used in both radio units and baseband are based on the latest silicon technology, and we are continuously developing energy-efficient hardware platforms with the latest silicon advancements.

Our transmitter power amplifiers use the most energy-efficient RF device technology and an optimized architecture according to each product variant.

Our software features help save energy in low traffic conditions by switching off power amplifiers, muting MIMO and Massive MIMO transceivers, shutting down individual capacity layers and muting radio resources with fast recovery when traffic increases.

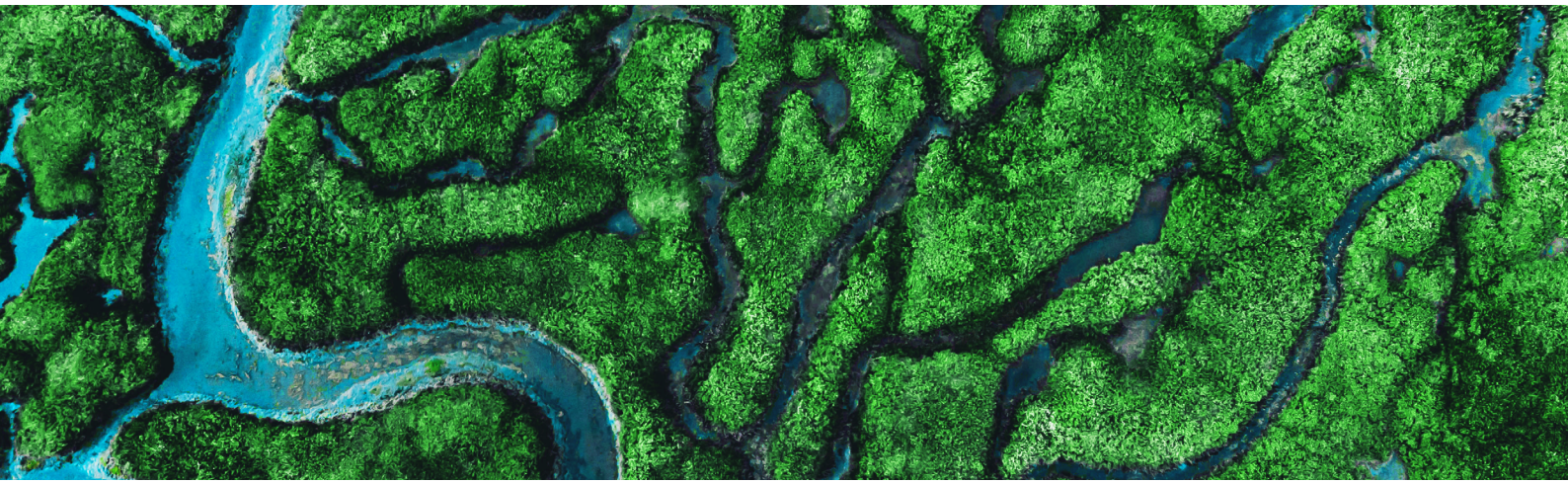
The advanced AI/ML-based capabilities of Nokia MantaRay SON automate the energy-saving RAN software features while ensuring that the energy optimizations have no impact on throughput and other key KPIs. We also provide monitoring and reporting of energy-related metrics with MantaRay NM.

Our network design, planning and optimization services ensure the best customer-defined balance between performance and energy efficiency. Nokia's Digital Design approach enables an optimized configuration for each individual cell in the network with overall lower transmit power. The advanced analytics guarantee that there is no performance degradation.

We have developed a portfolio of innovative site solutions that do not need active air-cooling such as the outdoor All-in-one cabinet and the Zero-footprint solution. Our site solutions also support renewable (solar) energy, which helps achieve additional OPEX savings and reduce carbon emissions.

Based on competitive benchmarking, the Nokia AirScale Baseband (CU/DU) provides the lowest power consumption per cell, per subscriber, and per Gbps. The new Nokia AirScale Habrok Massive MIMO radio units and AirScale Pandion remote radio heads match the industry benchmarks for energy efficiency.

We are continuously working on enhancing the energy efficiency further for the next generations of our radio network portfolio.



Glossary			
AC / DC	Alternating Current / Direct Current	**OPEX**	Operating Expenses
AI/ML	Artificial Intelligence / Machine Learning	**PA**	Power Amplifier
BTS	Base Station	**PDCCH**	Physical Downlink Control Channel
CDU	Coolant Distribution Unit	**PRB**	Physical Resource Block
CPU	Central Processing Unit	**QoS**	Quality of Service
CSP	Communications Service Provider	**RAN**	Radio Access Network
CU	Centralized Unit	**RF**	Radio Frequency
DU	Distributed Unit	**RRC**	Radio Resource Control
ESG	Environmental, Social, and Governance	**RRH**	Remote Radio Head
ESM	Energy Savings Management	**RU**	Radio Unit
ETSI	European Telecommunications Standards Institute	**SNMP**	Simple Network Management Protocol
FFR	Fast Frequency Reserve	**SoC**	System-on-Chip
GaN	Gallium Nitride	**SON**	Self-Organizing Networks
GIS	Geographic Information System	**SRS**	Sounding Reference Signal
GoB	Grid of Beams	**SSB**	Synchronization Signal Block
GSMA	GSM Association	**3GPP**	The 3rd Generation Partnership Project
HEX	Heat Exchanger	**TSO**	Transmission System Operator
KPI	Key Performance Indicator	**UE**	User Equipment
L1	Layer 1	**vCU**	Virtualized Centralized Unit
L2	Layer 2	**vDU**	Virtualized Distributed Unit
L3	Layer 3	**VPP**	Virtual Power Plant
µDTX	Micro Discontinuous Transmission		
MIMO	Multiple Input Multiple Output		
MU-MIMO	Multi-User MIMO		
NGMN	NGMN Alliance		
NM	Network Management		

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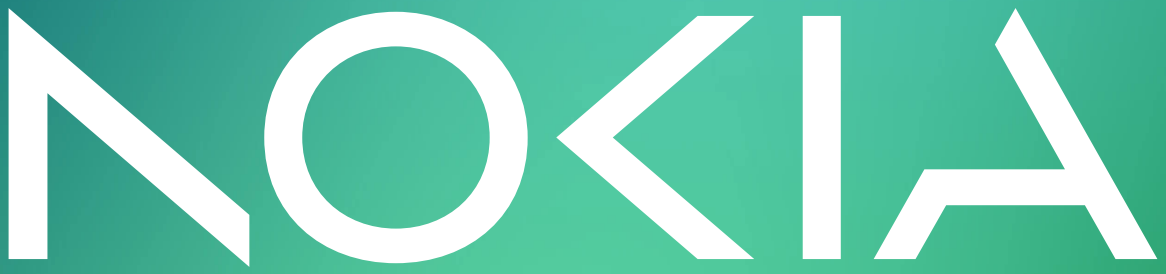

About Nokia

At Nokia, we create technology that helps the world act together.

As a B2B technology innovation leader, we are pioneering networks that sense, think and act by leveraging our work across mobile, fixed and cloud networks. In addition, we create value with intellectual property and long-term research, led by the award-winning Nokia Bell Labs.

Service providers, enterprises and partners worldwide trust Nokia to deliver secure, reliable and sustainable networks today – and work with us to create the digital services and applications of the future.