ZTE

Every Bit Going Extremely Green

2024

On the way to
Mobile Net Zero

ZTE CORPORATION

Foreword

From the rampant floods to the scorching heatwaves around the world, the necessity of taking climate action has never been more evident. Climate change presents an increasingly grave challenge to the survival and development of all humanity, propelling the protection of the natural environment into a race against time. Green and low-carbon initiatives have consequently become a common goal and mission across all industries. Amidst such significant changes, establishing a more resilient socio-economic system and a broader space for sustainable development has become a global issue. This also drives the green development strategies of the ICT (Information and Communication Technology) industry in a systematic way.

Reports and survey data from CDP (Carbon Disclosure Project) and GSMA Intelligence clearly showcase the ambitious vision of the entire telecommunications industry. Approximately 85% of global operators [1] have committed to the SBTi (Science Based Targets Initiative) to achieve net-zero emissions, with most aiming for the year 2050. Additionally, several operators have made even more proactive commitments; companies like Vodafone, Telefónica, Orange, and MTN have pledged to reach net-zero emissions by 2040.

The telecommunications industry accounts for about 1% of the global electricity consumption, which is equivalent to approximately 300 terawatt-hours annually. For operators, energy and electricity expenses make up about 20-40% of the total operating expenses and 80-90% of network expenditures (excluding site rental costs), making energy efficiency a core strategic focus within the telecom ecosystem. Many leading mobile network operators have recognized the importance of improving network solutions, where more efficient equipment is seen as a key standard for cost savings.

The ultimate goal that this white paper continuously explores is how to use the evolution of technologies to minimize the energy consumption per bit. This is not only a relentless pursuit but also an essential pathway for mobile networks to accelerate their transition towards net-zero carbon emissions.

Contents

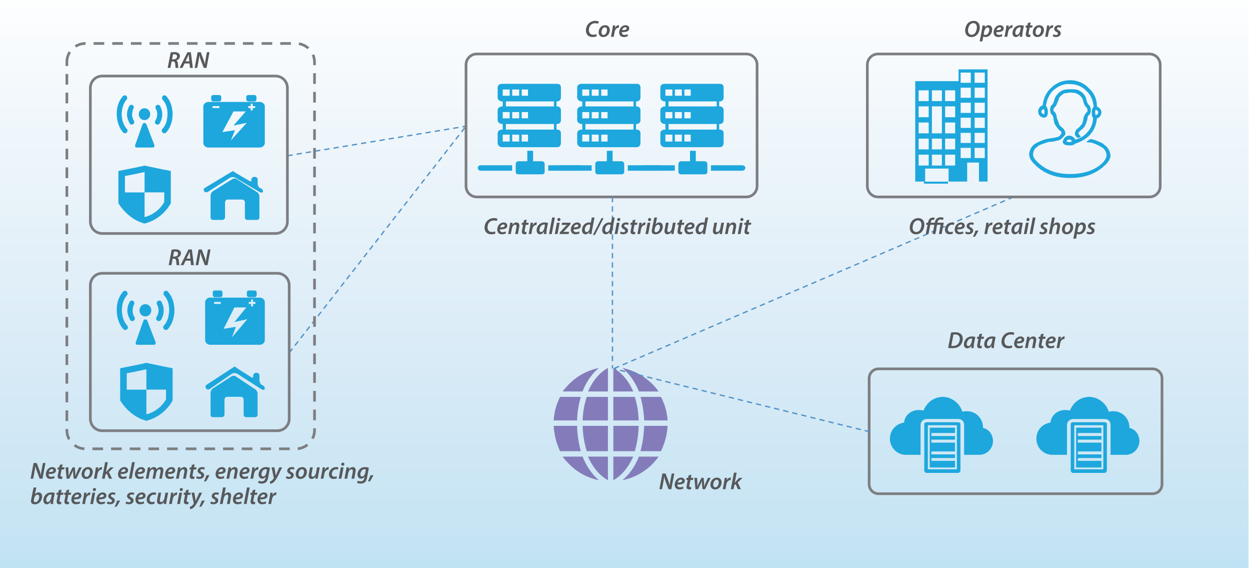
1 Our evolving approach to achieving Mobile Net Zero

In 2021, GSMA Intelligence released an energy efficiency benchmarking service for mobile networks. The unique analytical approach allows operators to measure the relative efficiency of their networks. The direct energy consumption of the operators can be categorized into four groups[2]:

- RAN energy consumption: energy consumed by the RAN (Radio Access Network). This includes BTS, Node B, eNodeB and gNodeB energy usage and all associated infrastructure energy usage such as from air-conditioning, inverters and rectifiers. It includes energy usage from repeaters and all energy consumption associated with backhaul transport.
- Core energy consumption: energy consumed by the core network related to the mobile network. This includes the RNC, BSCs, MSC, SGSN, GGSN, HLR, SMS-C, MMS-C, MME, Serving Gateway, and all associated infrastructure energy usage as from air-conditioning, inverters, and rectifiers.
- Data center energy consumption: energy consumed by data centers, which are the physical sites that host operators' IT, including OSS and BSS and intranet infrastructure.
- Other operations: energy consumed by the mobile operator for its own operations. This includes offices, shops, retail activity and logistics.

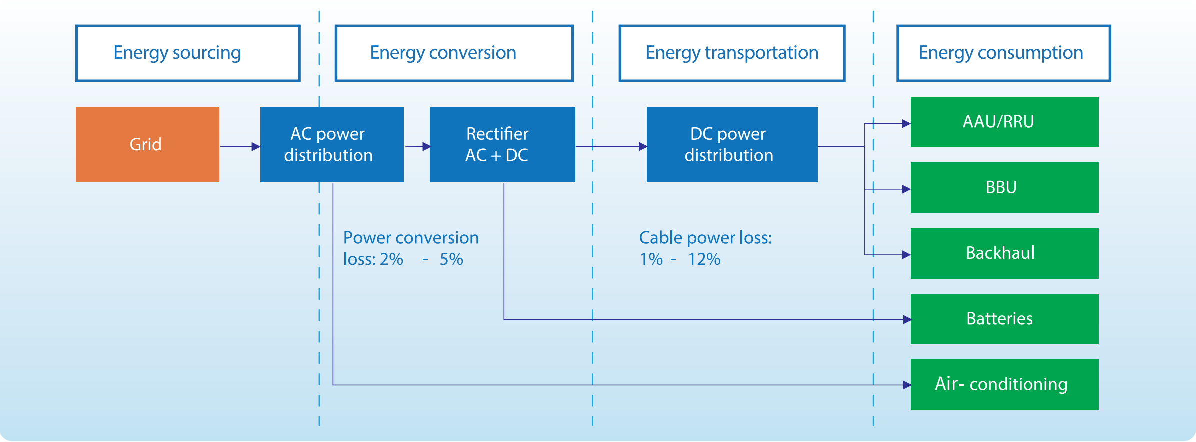
Most of the energy (more than 70%) is used in the RAN, in certain operators, it even goes above 80%. The main goal for operators striving for Mobile Net Zero is to lower the RAN's energy usage.

Figure 1 Basic network architecture: where energy is used



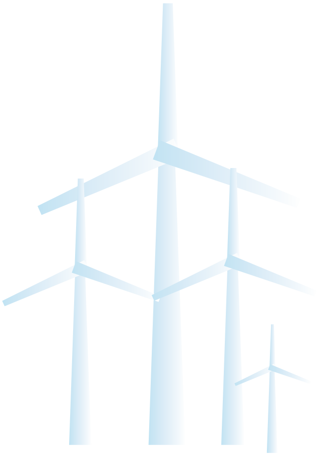
The site passive infrastructure system, which includes things like air conditioning, power supplies, transmission, etc., makes up the first portion of the RAN's energy consumption. The other component is the energy consumption of the primary equipment, which includes things like radio frequency units (RRUs/AAUs) and baseband units (BBUs). Each part's percentage of energy consumption will differ depending on a number of variables, including the machine room layout, traffic patterns, and surrounding conditions. The NGMN Energy Efficiency Report[3] states that the energy used by cooling systems (air conditioning) makes up roughly 40% of the energy used on the site, power distribution and backhaul energy use makes up 5%–20%, and the energy used by the primary communication equipment makes up more than 50%.

Figure 2 End-to-end energy loss from grid to the RAN



Every two to three years, hardware equipment experiences tremendous development due to the ongoing advancements in hardware technology, architecture, and materials. This leads to a notable reduction in power consumption within the same requirements. Energy consumption will be drastically decreased under various network loads thanks to improved architectures, integrated and high-efficiency chips, and sophisticated algorithms. Operators acknowledge that implementing such energy-efficient equipment during network expansion or modernization is a good approach to lower network energy usage.

Thus, a strategy to further increase network efficiency is to further overlay energy-saving technology, which lowers network redundancy capacity by turning off some radio units or parts of components and enables network energy consumption to meet load demand. The accurate application of energy-saving technology is made possible by the synchronization of hardware architecture and software algorithms, constant improvement

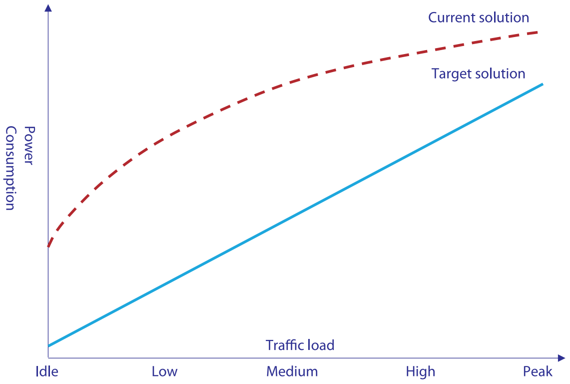


of shutdown depth and granularity. As a result, network energy consumption gradually approaches a linear change in response to business demand [4].

It is crucial to assess energy efficiency while also taking into account the site's passive infrastructures. For example, rectifiers' efficiency can rise from 90% to 98% by increasing their conversion efficiency. Using lithium batteries instead of conventional lead-acid batteries as energy storage devices can lower the energy used for air conditioning cooling. It is possible to increase temperature control efficiency by up to 80% by using more integrated outside cabinets.

Reaching the Mobile Net Zero target can be facilitated by maximizing the decrease of energy usage in the RAN through multi-dimensional coordination.

Figure 3 near-linear solution for Traffic/Power consumption



2 Evolving towards ultra-high efficiency Radios

The energy consumption of a base station can be divided into two main parts: the Radio Frequency Unit (RRU/AAU) and the Baseband Unit (BBU). Taking a single-band three-sector site as an example, the power consumption of the RF unit accounts for more than 70% of the total power consumption of the base station. As the number of frequency bands increases, the RF equipment also expands, and its energy consumption proportion accounts for over 90%, making it the primary component of base station energy usage.

The power consumption of the RF unit mainly comes from modules including PA (Power Amplifier), transceiver, DIF (Digital Intermediate Frequency), baseband, and power supply. The total power consumption varies with the service load, and the energy consumption ratio of each module also changes accordingly. However, the PA consistently remains the primary contributor to power consumption. Taking the industry's typical dual-band UBR (Ultra-Broadband Radio) with 4T4R 1.8GHz + 2.1GHz and 4×120W configuration as an example, under different loads, the power consumption of the PA always remains above 65%, and can approach 90% at peak load. Reducing power amplifier energy consumption is crucial for decreasing base station power consumption. The key to reducing base station power consumption lies in improving the efficiency of the PA, as the PA's efficiency directly determines its energy consumption.

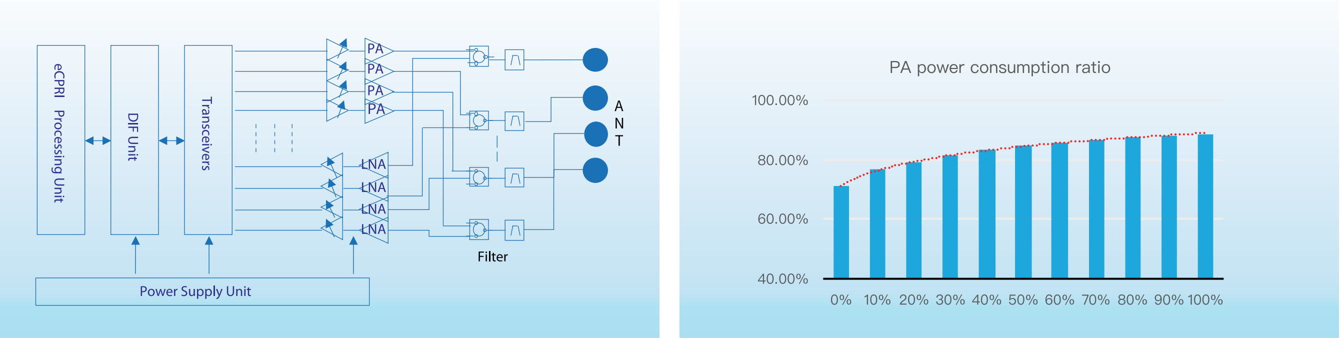


Figure 4 RRU architecture and PA power consumption ratio

2.1 Efficiency bottlenecks of conventional PA architecture

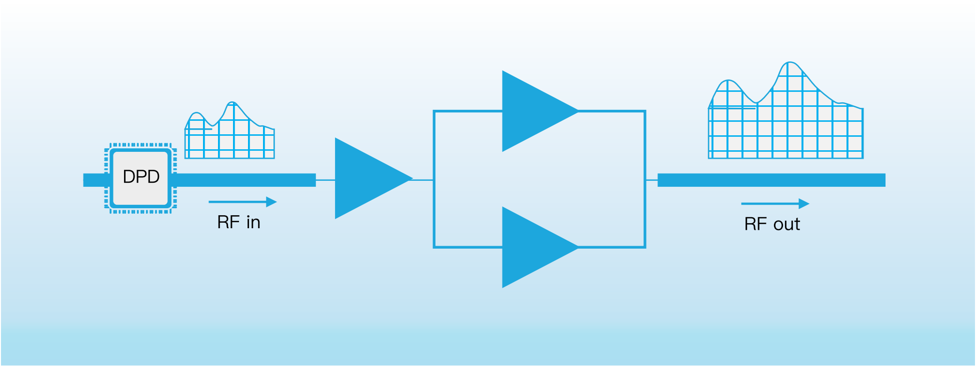
LDMOS (Laterally-Diffused Metal-Oxide Semiconductor) power transistors, made with Si technology, have been the mainstream RF amplifiers for 2G, 3G, and 4G mobile communication base stations. After years of technical evolution and product iteration, their parasitic parameters are large, power density is low, and RF performance has essentially reached its limit, making it difficult to further improve efficiency.

GaN (Gallium Nitride), as a third-generation compound semiconductor, has characteristics such as high working frequency, high power density, and high efficiency. Additionally, due to its unique heat dissipation and wide bandwidth characteristics, GaN can withstand greater thermal consumption and power, providing good reliability. PA based on GaN have been widely used in multi-antenna Massive MIMO 5G base stations, effectively improving PA efficiency and reducing overall power consumption. A complete transition from LDMOS to GaN in RRU power amplifiers, and continuous innovation in the high-efficiency GaN power amplifier architecture, can further improve power amplifier efficiency.

Industry-standard PA uses the Doherty architecture, which comprises one driver stage power transistor and two final stage power transistors, known as the Peak and Carry transistors. These two transistors have different operating states and under the excitation of the modulated signal, the signal is separately amplified by these two power transistors.

The characteristic of this architecture is that it is simple and easy to implement. It can maintain high efficiency at rated power, but as the output power decreases, the efficiency of the power amplifier drops rapidly. Moreover, the efficiency improvement of traditional architecture power amplifiers mainly relies on the improvement of power transistor efficiency. After years of iterative evolution, they have reached an efficiency bottleneck. There isn't much potential for future efficiency improvements, and cannot meet industry energy-saving expectations.

Figure 5 Doherty PA architecture



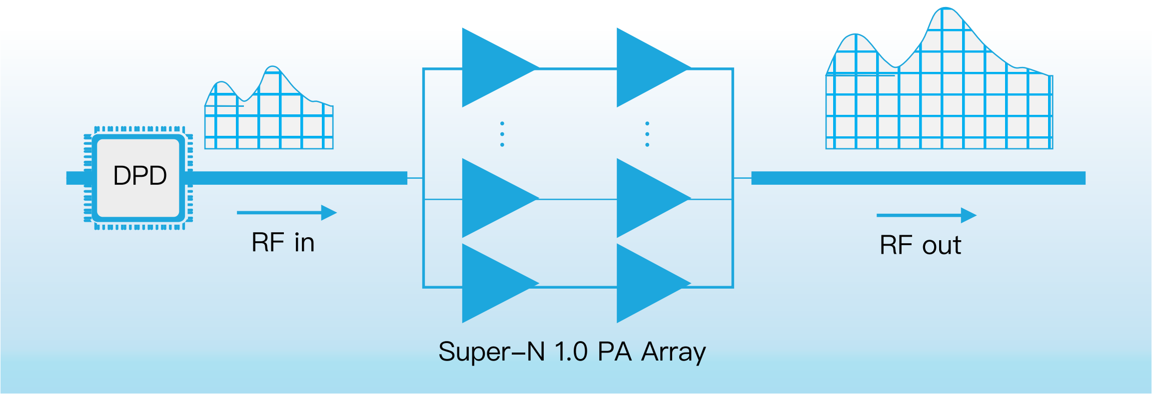
2.2 The brand-new Super-N architecture for PA efficiency enhancement

To overcome the PA efficiency bottleneck, the industry-first "dense transistor array PA architecture" of ZTE Super-N 1.0 PA has been adopted to move away from the traditional PA architecture. Unlike the traditional PA that uses large dies, the "dense

ransistor array PA architecture" employs multiple small dies to achieve multi-stage and multi-path amplification, greatly improving the efficiency of the PA. Compared to the efficiency of traditional architecture, there is an increase of 8% to 10%.

- The multi-stage, multi-path design under the dense transistor array architecture can achieve multiple high-efficiency points, thereby pushing the overall PA efficiency higher, whereas traditional PAs only have a single high-efficiency point, resulting in overall lower efficiency.
- With smaller die packaging, there is fewer parasitic parameters and less loss, resulting in a higher base efficiency.

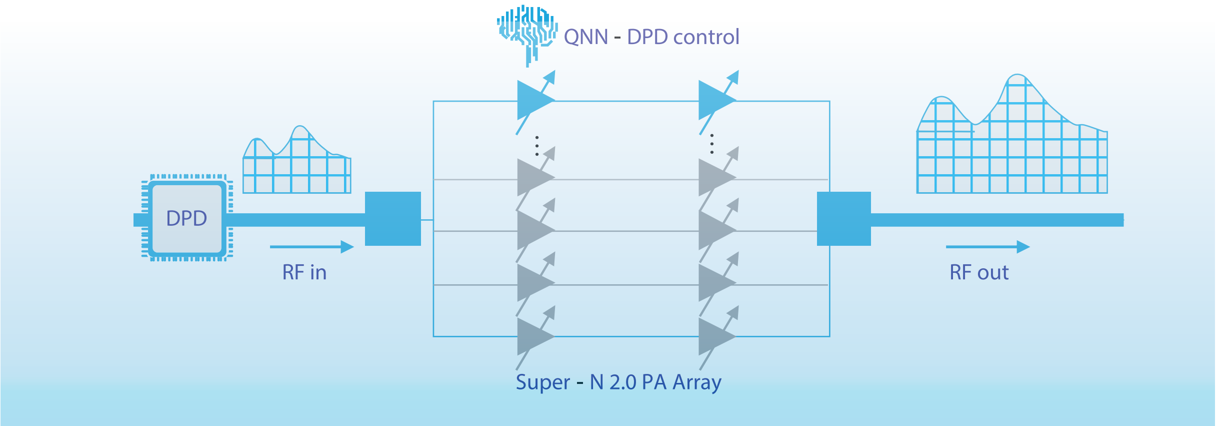
Figure 6 Super-N 1.0 architecture



Although the Super-N 1.0 PA significantly increases the PA efficiency, similar to traditional PAs, it also experiences a rapid decline in efficiency as the output load decreases. Considering that in actual networks the vast majority of sites and time are operating under lower loads, improving power amplifier efficiency at low loads is more important for energy saving. This has been a long-standing challenge in the industry that is difficult to resolve.

Extensive research into low-load PA efficiency has led to significant breakthroughs and the introduction of the Super-N 2.0 constant-efficiency PA architecture, greatly enhancing efficiency under low loads. Based on the 1.0 version, Super-N 2.0 PA uses an even smaller and more densely packed PA transistor array, and adopts an "on-demand" adaptive activation method for the PA dies. This allows for the use of fewer dies under low loads, reducing the power amplifier saturation point fallback. In coordination with new Super-N 2.0 architecture, QNN-DPD (Quasi-Neural Networks-Digital Pre-Distortion) technology is developed to detect the signal and characteristics of the PA transistor array in real time, achieve adaptive and precise matching online, and enable digital-analog collaborative control to improve PA efficiency under low load, thus achieving almost constant efficiency.

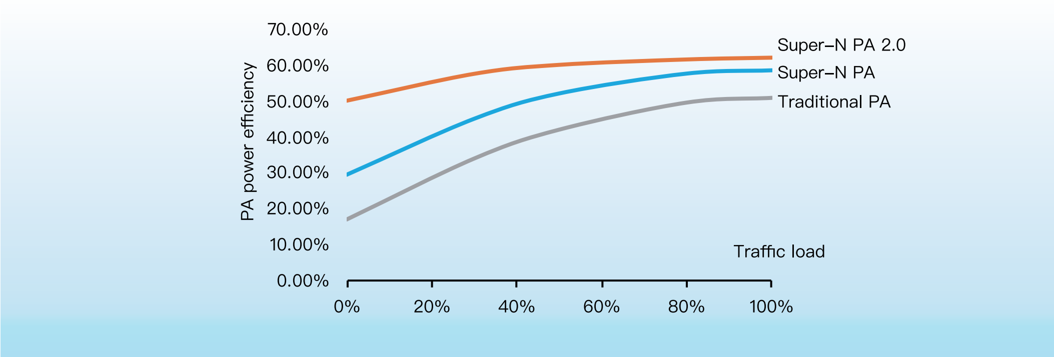
Figure 7 Super-N 2.0 architecture



Compared to traditional industry PAs, the Super-N 2.0 PA possesses two main characteristics: "high efficiency" and "constant efficiency."

- High efficiency: Efficiency at all loads is higher than the industry standard. with 10% load efficiency being three times the industry standard and 30% load efficiency being 1.5 times the industry standard.
- Constant efficiency: The efficiency remains nearly constant when the load is above 30%.

Figure 8 Comparison of PA efficiency under different architectures

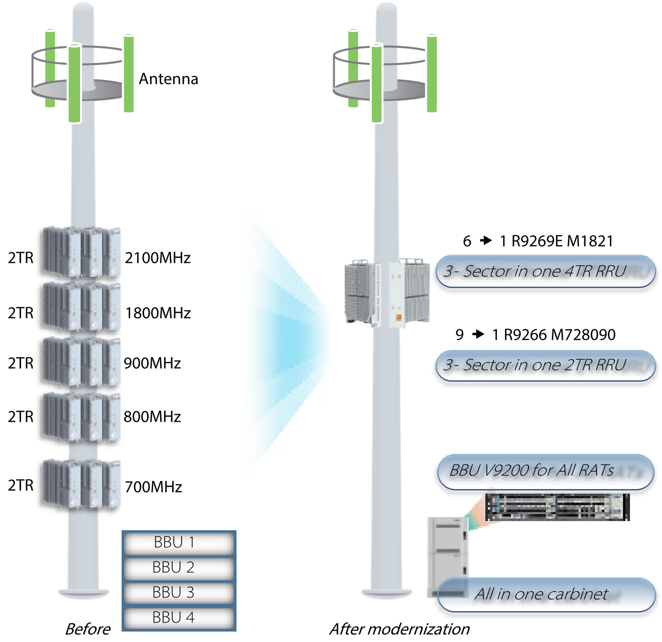


2.3 Evolution of full series product, 50% energy consumption reduction with site modernization

To effectively reduce the daily energy consumption of sites, the modernization of sites is crucial. Using new, efficient products to replace outdated and inefficient equipment in the existing network can significantly reduce network energy consumption. With technological advancements, including higher integrated digital intermediate frequency and transceiver chips, multi-band technology allows for the combination of multipledifferent frequency band RF units into one multi-band physical unit. This not only improves energy efficiency but also reduces the size and weight of RF equipment.

Generally, site leasing contracts are usually based on the site's footprint (unit number, volume, and weight). Modernizing the sites can significantly reduce the Total Cost of Ownership (TCO), and this transformation can help operators move towards Net Zero carbon emissions. Taking the scenario of low-band 2T3S in 700M+800M+900M, and mid-band 4T3S in 1.8G+2.1G as an example, with current technology, only one 6T6R (700M+800M+900M) UBR and one 12T12R (1.8G+2.1G) UBR are sufficient for the modernization of the RF part. Compared to traditional single-band, single-sector equipment, the ETSI power consumption is reduced by 50%.

Figure 9 Site modernization



Details	Before	Modernization
RRU	3 x 2TR @ 700 3 x 2TR @ 800 3 x 2TR @ 900 3 x 2TR @ 1800 3 x 2TR @ 2100	1 x 6TR UBR @ 728090 1 x 12TR UBR @ 1821
PA	Doherty	Super - N 2.0
Num	15	2
Power consumption @ ETSI	100%	50%

3 Energy saving technologies focusing on refinement, automation and orchestration

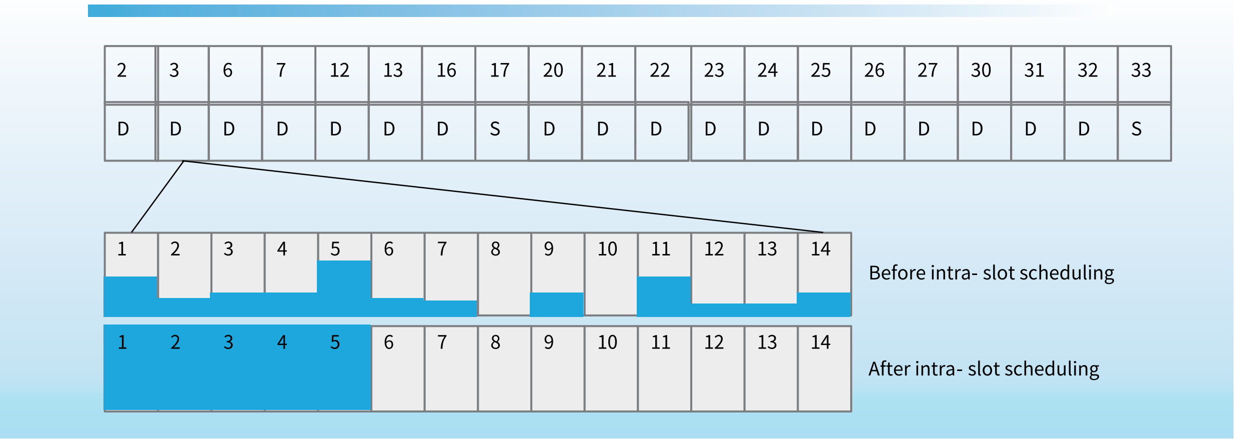
3.1 Equipment-level energy saving technologies advances in depth and precision

With the deployment and improvement of mobile network, the multi-frequency and multi-mode overlapping coverage mobile network has been formed. The key technology point of energy-saving technology is the ability to turn off certain radios and reduce network redundancy capacity, matching network energy consumption with the traffic load distributed across the network. Concurrently, energy-saving features need to be scenario-based and user-centered by deploying energy-saving features in accordance with real-time traffic distribution. "Watt follows bit" energy-saving scheme will be realized from multi-domain method (time, space, and frequency).

- For time-domain: intra-slot scheduling and shut down

By aggregating the transmitted data in the time domain and instantly shutting off the PAs during low traffic periods, power consumption of radios will be reduced. However, the conventional aggregation granularity is measured inter-slot, this results in a rise of network latency. Symbol-level aggregation within timeslot is necessary to maximize the energy-saving effect while guaranteeing service performance. This will increase the number of idle symbols and improve the PA shutdownable time without delay impact.

Figure 10 Intra-slot scheduling



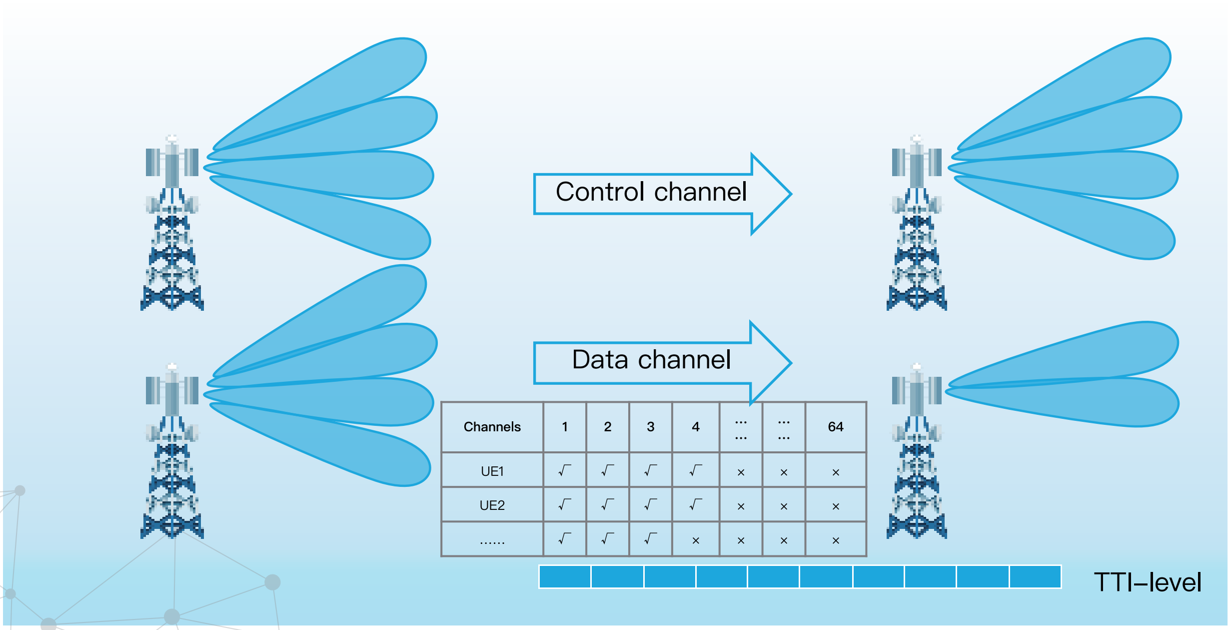
2	3	6	7	12	13	16	17	20	21	22	23	24	25	26	27	30	31	32	33
D	D	D	D	D	D	D	S	D	D	D	D	D	D	D	D	D	D	D	S

- For space-domain: TTI-level channel shut down

When a sector has low traffic, space-domain energy conservation involves turning off some channels including PAs and transceivers in order to save energy. Conventional channel shutdown only uses cell load as the entry and exit criteria. Even though increasing power spectral density can mitigate the transmission power loss effect of channel shut down, network coverage impacts especially for edge users.

As a result, energy saving in the space domain must advance to response times of milliseconds or even symbols, incorporating weight value shaping and quick channel state matching of coding modulation techniques. It is possible to completely utilize potential energy-saving spaces while promptly reacting to exit space-domain energy saving mode during traffic surges or data transfer by fully integrating user distribution and channel quality information into the network.

Figure 11 TTI-level channel shutdown



Channels	1	2	3	4	……	……	64
UE1	√	√	√	√	×	×	×
UE2	√	√	√	√	×	×	×
……	√	√	√	×	×	×	×

- For frequency-domain: extreme dormancy with hibernation

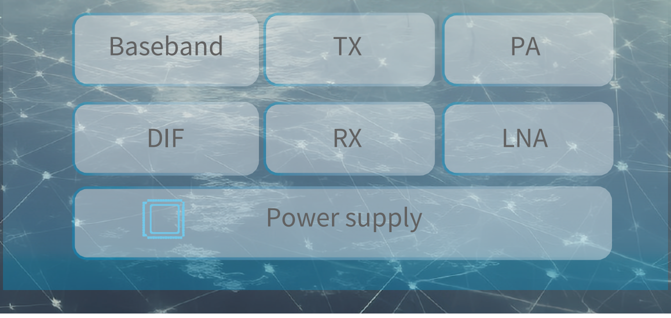
To reduce the energy consumption of the RAN while maintaining stable network KPIs, MNOs have explored the deployment of new RAN equipment with reduced load independent power consumption as well as the optimization of network capacity according to traffic demand by switching off temporarily underutilized carriers.

To investigate the possibility of optimizing BS energy consumption further, the concept of extreme deep dormancy is explored. Even when the BS is in deep dormancy, the active components of AAU/RRU still consumes dozens of watts of power. To achieve extreme energy saving, the BS could be put in a state of hibernation. This is defined as the state of reduced power consumption achieved by muting all the modules of the AAU/RRU except for timing module, microcontroller of the power supply. The power consumption of the AAU/RRU will be significantly lower when extreme dormancy is activated, less than 5 watt.

But there are also major obstacles in the way of technical improvement, primarily because of the wear and tear on the equipment caused by numerous restarts. To further advance the development of hibernation technology, ongoing study and exploration are needed in the fields of chip SoC (System on Chip), hardware shutdown, and software protection.

- Full power supply reliability argumentation, including switch-on/off stress, thermal cycling stress, low-temperature endurance, and negative pressure backfill.
- Automatic energy-saving execution strategy control based on power module device environment characteristics
- Remote software upgrade, self-check, and rollback functions for power supply module
- Internal positive bias circuits in the power sub-system that optimize the gate voltage DAC's internal negative voltage pathway design by countering the negative pressure backfill brought on by the power amplifier's parasitic resistance.

Figure 12 Hibernation: extreme dormancy



3.2 Leverage AI/ML and automation for maximized traffic performance with minimized energy use.

- Energy efficiency is the ultimate goal

Advancement in equipment power efficiency and network energy performance must be considered from an end-to-end perspective. The key to network energy efficiency evaluation lies in selecting appropriate indicators to describe the rationality and optimizability of network energy consumption. According to the definition of the ETSI (European Telecommunications Standards Institute), network energy efficiency refers to the effective output provided after consuming a unit of energy. The effective output can be traffic throughput (kbps), latency (ms), or coverage range (m/km), depending on different network application scenarios. For the eMBB scenario in communication networks, the effective output is mainly network traffic, expressed in GBite/Kwh.

However, as the network develops, new services and scenarios continue to emerge, and the performance requirements for different services are completely different. The traditional "network-centric" approach has been replaced by the "user-centric" approach, and single-dimensional traffic efficiency can no longer represent network energy consumption and efficiency [6]. It is necessary to move towards multi-dimensional comprehensive evaluation, including traffic, experience, and energy-saving enablement.

To more comprehensively obtain network energy efficiency and guide corresponding network energy-saving strategies, it is necessary to identify the most energy-efficient network for business carrying. The recognition system for network energy efficiency must be constantly updated and evolved to adapt to the different stages and scene-specific service foci of network development. A multi-dimensional energy efficiency model should be constructed, and the optimal network layer should be selected as the guiding factor for subsequent energy-saving policy choices. Therefore, constructing a network energy efficiency model requires continuous expansion from the perspectives of scenario-based, normalized, and multi-dimensional:

- Scenario-based: Different network scenarios have different network outputs, and network energy efficiency indicators also change accordingly.
- Normalized: When analyzing the influence of various factors on network energy efficiency, normalization processing can be performed through regression analysis and data fitting according to actual analysis needs.
- Multi-dimensional: Different business scenarios focus on different effective outputs, and even for the same business scenario, the effective output is not a single dimension, but possibly multiple dimensions.

In summary, the effective output of the network mainly includes business volume and business quality, and a generalized formula can be expressed as follows:

$$\text{Energy Efficiency} = \frac{\text{Service(Quantity,Quality)}}{\text{Energy consumption}}$$

- Full-scene recognition of energy saving

With the continuous development of machine learning, IT (Information Technology) technology can be effectively applied to CT (communication technology) domains to address the challenges of deep energy conservation deployment. By utilizing AI and big data analysis, we can achieve scenario recognition, deeply learn the load trend in small areas, and organically coordinate time, space, frequency, and power domain energy-saving strategies.

This approach results in "one cell, one policy," while simultaneously evaluating network KPIs in real-time to ensure performance, achieving the optimal balance between energy consumption and performance. This solution can be widely applied to various network coverage scenarios, including high-traffic areas such as universities, traffic arteries, and commercial districts.

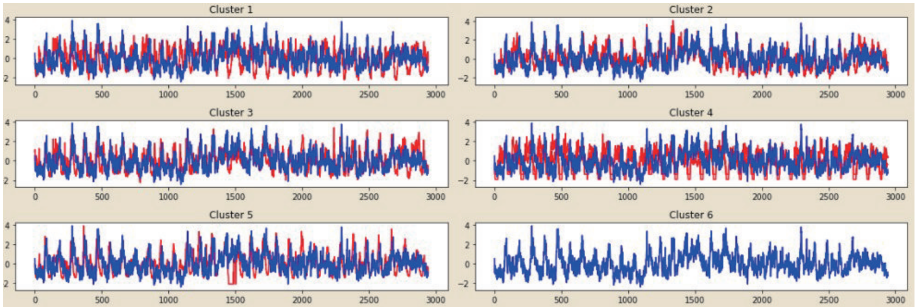
In data processing, a wide table is used for data collection and cleaning, gathering performance data, cell scene data, and configuration data. Currently, telecom single-domain data is mainly cleaning, future plans call for the collection of cross-domain data, including traffic and weather.

The distribution of network traffic in different application scenarios exhibits certain aggregation patterns, including weekly and daily trends. By obtaining network capacity information and other relevant information from existing network data, we can perform clustering to extract scene features.

- Colleges/offices: typically show a weekly pattern with higher traffic during weekdays and lower traffic on weekends, with both weekdays and weekends having high traffic peaks only in the afternoon.
- Shopping malls/parks: generally exhibit weekly patterns with lower traffic during weekdays and higher traffic on weekends, especially in the evenings, with a higher load on Saturdays than on Sundays.
- Residential areas: similar traffic patterns on weekdays and weekends, with high traffic peaks around noon and in the evenings.
- Metros: double-peak traffic pattern during weekdays, with high traffic peaks during morning and evening rush hours.

By performing clustering analysis on a large number of samples collected by the network and using the K-Means algorithm for time series waveform clustering, we can obtain a generalized model. Through waveform discrete separation, we can derive a rule sequence that can be used for generalized prediction. By observing the waveform of the cluster center points, we can clearly see the distinct pattern differences between different classifications.

Figure 13 Cell generalized classification model



The red line in the figure represents the data collected from newly added cells, while the blue line represents the prediction results after the clustering algorithm. To a certain extent, it can encompass the changes in traffic for new cells, including overall trends and extreme values. However, *there is still room for improvement in terms of overall precision, which requires further optimization such as smoothing and alignment. Nevertheless, it can effectively distinguish differences in traffic between weekdays and weekends, meeting the initial requirements for scene recognition.*

- Optimal one cell, one policy

Based on the predicted trend of business variations in cells, and taking into account the needs of MNOs, we distinguish coverage scenarios, whitelists, blacklists, and value areas, generating the optimal energy-saving strategy for energy-saving small areas.

- Traffic load prediction analysis: traffic load prediction by AI is achieved through deep learning; based on the predicted results of the traffic load of each cell, low-load energy-saving cells are screened out.
- Traffic allocation ability analysis: the expand capacity layer and basic coverage and capacity layer are distinguished, and the overlapping coverage layer cells are selected as compensation cells, used to allocate service load.

- Energy-saving policy matching: based on policy rules (switch-off threshold, time period, duration, and power-saving features), energy-saving policies are generated.
- Policy iteration self-optimization: based on the overall scenario traffic model, network energy-saving effects and KPI trends are analyzed, and the learning is strengthened online, continuously iterating and optimizing to reach the optimal balance point between energy saving and system performance.

4 Towards zero carbon through integrity site solutions

In traditional sites, the power consumption of site support equipment, mainly driven by the air-conditioning, can be as great as 40% of the total site energy consumption with the precise ratio being influenced by a range of environmental factors [5]. In a cooler environment with passive cooling the air conditioning load is small, in a warmer external environment the air conditioning load would be significantly higher. Novel site design solutions can determine which sites really need air conditioning and a temperature control system, so that these are deployed only where required.

Historically, access site deployment involved placing site support equipment indoors while the telecoms equipment (e.g., AAUs, RRUs and antennae) were located outdoors. With modular site architectures, site support equipment could be moved from traditional indoor sites to outdoor sites. Shifting some of this equipment outdoors together with further deployment of outdoor poles results in reduced energy consumption by outdoor cooling. This approach also reduces power loss due to the conversion for power continuity, which can be further minimized with the deployment of state-of-the-art power solutions that have high conversion efficiency.

Figure 14 Simplified site from indoor to outdoor

4.1 The site energy efficiency improvement through simplified and modular site architecture

Switching off legacy radio access technologies (RATs) has been associated with transitions to simpler architectures and with novel hardware able to run at higher temperatures, which allows the deployment of more modular components outdoors rather than indoors. A variant of this approach involved placing network components, e.g., antennas, radio, and Baseband units (BBUs), which can support multiple technologies, in one centralized piece of equipment, without adversely affecting user experience on the live network.

It is important to highlight that achieving low-cost heat dissipation control, efficient heat management, and high reliability in a simplified site operating in different environmental conditions, hardware configurations and processing requirements, is a challenge, which requires system design methods based on accurate thermal simulation design and integrated performance verification capabilities.

With modular design, all-in-one outdoor cabinet uses new generation of lithium batteries and high-efficiency power supplies to improve the site's power supply efficiency. It also uses flexible, diversified near-end temperature control equipment and a cold source near the heat source to significantly reduce cooling energy consumption. The site's capacity can be upgraded seamlessly to support long-term evolution and future expansion. All-on-pole site eliminates the need for air conditioning and equipment room, which is suitable for rural coverage. It is possible to achieve green energy supply by using only two solar panels, realizing zero carbon site deployment.

Figure 15 Simplest outdoor sites

All-in-one cabinet site
@ China Mobile

All-on-pole site
@ Nigeria

Going forwards, to evaluate the energy-saving effectiveness of these simplified architectures fully, it is necessary to reach a consensus on the scope of the SEE (site energy efficiency).

4.2 Indoor site cooling efficiency improvement through liquid cooling

Energy usage at a site can be greatly influenced by cooling systems, which remove heat produced by the equipment. In terms of cooling solutions, outdoor sites can benefit from free cooling; indoor sites still need innovative cooling technology. Some mobile network operators view liquid cooling technology as a practical means of cutting energy usage in the indoor site, especially with the increasing concentration of BBU deployments.

Cabinet liquid cooling may be the best solution currently. The BBU equipment is placed in the liquid cooling cabinet with liquid cooling pipes on the back of the cabinet. A CDU (Coolant Distribution Unit) and a water pump are used to circulate the liquid in the cooling pipes continuously so that the heat generated by the BBU equipment is absorbed into the liquid of the cooling pipes, then discharged into the atmosphere by the external radiator, resulting in heat dissipation. After implementing cabinet liquid cooling, overall PUE is reduced by over 20%, and air conditioning power consumption is reduced by over 60%.

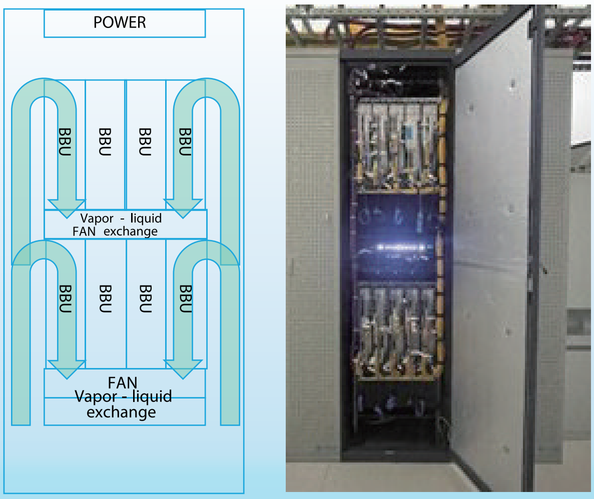


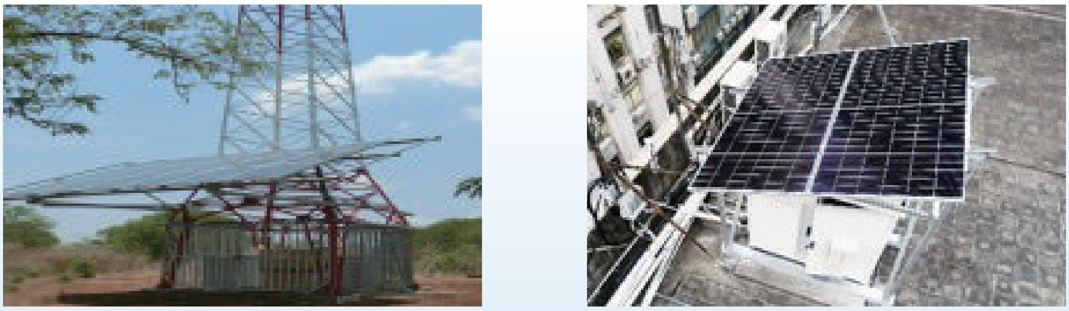
Figure 16 Cabinet-level liquid cooling @ China Mobile

4.3 Renewable power supply for sustainable future

For MNOs, renewables are a key initiative to leverage onsite power generation to reduce the power from the grid, as well as reduce carbon emissions from diesel generators for off-grid RAN sites. MNOs have sought innovative solutions to the challenge of generating renewable power directly at RAN sites in rural or remote areas without access to power grids or where there are frequent power outages while avoiding using fossil fuels onsite.

Unfortunately, energy production technologies still have high deployment costs, and only some sites are suitable for renewable implementation due to limiting factors e.g., shading, space, wind speed, etc. The new generation sPV (smart photovoltaic) solution supports rapid introduction of green and clean energy sources for station, cabinet, and pole sites. Each solar panel is equipped with sPV modules, implementing MPPT (maximum power point tracking) for single components, and maximizing solar energy generation while effectively reducing the impact of shading on solar energy generation, thereby improving overall power generation by 20%+.

Figure 17 Full scenario solar onsite



Solar on pole

Solar on cabinet

Solar on site

Solar on industry park

Conclusions

Achieving "peak carbon and carbon neutrality" is a significant strategic decision on a global scale and a solemn commitment to building a shared future for humanity. While further efforts are needed to reduce emissions and achieve the Mobile Net Zero by 2050, the mobile industry continues to make meaningful progress in decoupling data traffic from power consumption and carbon emissions. In addition to leveraging operational efficiency, operators are shifting towards more renewable energy sources, with 24% of total power consumption in 2022 coming from renewable energy [1]. The introduction of clean energy has effectively reduced the carbon footprint of wireless networks.

Within the broad ICT landscape, communication networks will be important enablers for many industries to achieve full digital transformation and provide networked, digitized, and intelligent technological means for industry digitization and sustainable development. According to the GeSI (Global Enabling Sustainability Initiative), 5G networks can provide a 1:10 leverage to reduce 20% of global carbon emissions over the next decade by empowering other industries.

In the future, wireless communication will utilize higher frequency bands as signal carriers, achieving data rates in the terabits per second range. Simultaneously, new business demands such as holographic communication, intelligent interaction, sensory connectivity, digital twins, and communication perception will continue to emerge, resulting in a hundred-fold or even thousand-fold increase in network traffic. Balancing the increase in data with minimal power consumption requires the continuous integration of green design concepts, constant exploration of energy-saving and carbon reduction measures, and the pursuit of technological innovation. By enhancing communication network energy efficiency while ensuring optimum performance and experience, we can actively promote the transformation of the economy towards intelligence, supporting the achievement of net-zero carbon goals.

Glossary

ABBREVIATIONS	FULL NAME
AAU	Active Antenna Unit
AI	Artificial Intelligence
BBU	Building Baseband Unit
BSS	Business Support System
CT	Communication Technology
DIF	Digital Intermediate Frequency
DPD	Digital Pre-Distortion
eCPRI	Enhanced Common Public Radio Interface
EE	Energy Efficiency
ETSI	European Telecommunications Standards Institute
GaN	Gallium Nitride
GeSI	Global Enabling Sustainability Initiative
ICT	Information and Communications Technology
IT	Information Technology
ITU	International Telecommunication Union
KPI	Key Performance Indicator
LDMOS	Laterally-Diffused Metal-Oxide Semiconductor
LSTM	Long Short-Term Memory
LTE	Long Term Evolution
MIMO	Multiple Input Multiple Output
ML	Machine Learning
MMTC	Massive Machine Type of Communication
MR	Measurement Report
MNO	Mobile Network Operator
MPPT	Maximum Power Point Tracking
MTO	Multinational Telecom Operator
NR	New Radio
OSS	Operation Support System
PA	Power Amplifier
QNN-DPD	Quasi-Neural Networks-Digital Pre-Distortion
RAN	Radio Access Network
RRU	Remote Radio Unit
SEE	Site Energy Efficiency

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