HUAWEI

Building Green Networks
to Lighten Up the Way
to a Low-Carbon Future

GREEN 5G WHITE PAPER

CONTENTS

01 Introduction

Climate change is a global challenge. Countries must cooperate closely to develop a low-carbon economy. To this end, 189 countries have joined the Paris Agreement, and the world's major economies have all made commitments to carbon neutrality. The European Union (EU) has established a long-term strategy for achieving carbon neutrality by 2050, making it a clear focus in almost all of its policies. As a developing country, China has pledged to peak its carbon emissions by 2030 and become carbon neutral by 2060. After returning to the agreement in 2021, the United States is also more on track now than it was following its withdrawal in 2019.

The ICT industry is the first to respond to the Paris Agreement, moving both itself and its verticals toward carbon emission goals.

Communications contribute to non-ICT carbon emissions. As the world has moved from 2G and 3G to 4G, and now 5G, mobile services have expanded from voice calls and text messages to HD voice calls, mobile videos, personal applications, and platform services in many new fields, becoming an essential part of our daily lives. Such a diverse range of communications has always played an important role. In particular, 5G has already emerged as a new information infrastructure to enable digital intelligence in both production and operations across a wide range of industries, helping them optimize processes, control precision, and operations. One huge benefit from such progress is the substantial improvement in energy efficiency in social and economic activities, bringing our planet closer to the low carbon targets. In its report The Enablement Effect, GSMA showed that "with a European and North American scope, mobile technologies had a 1:5 enablement ratio compared to the footprint of the industry in 2015." This means that one kWh of power used by mobile networks has led to a 5 kWh reduction of electricity consumption in other industries. GSMA believes this ratio will further rise to 1:10 by 2025.

ICT carbon emissions have continuously decreased with swift action towards carbon neutrality. Many operators, such as Deutsche Telekom, Vodafone, France Telecom, Telefonica, China Mobile, China Telecom, and China Unicom, have given "green" growth a high priority on their strategic agendas.

Trends and interest towards carbon neutrality are growing. The ITU has made the reduction of ICT carbon emissions by more than 45% a clear target for 2030. Many operators have announced their own carbon neutrality targets and the action plans to deliver these targets.

In response to the above concerns, Huawei releases this Green 5G White Paper. It aims to facilitate joint industry efforts to develop effective systems for measuring network energy efficiency and to explore new technical directions for green networks, helping achieve carbon peak and carbon neutrality.

02 Green 5G Leads to a Low-Carbon Future

5G networks are developing rapidly. More than 176 operators have deployed 5G networks, bringing 5G services to more than 460 million people worldwide. 50 of these operators have even deployed 5G FWA[1] services. 5G has been applied extensively throughout vertical industries, and 5G home broadband subscribers now exceeds 1.2 million. While gaining fast momentum in ToC, ToB, and ToH, 5G networks continuously evolve to better fulfill the increasing demand for network services.

Operators need to develop networks that can deliver premium services to both individual and enterprise users while supporting the ambition towards a carbon peak and carbon neutrality. This means that, in addition to chasing high performance in experience and coverage, operators will need to focus heavily on going "green" while they scale up 5G business.

We have moved to purpose a green network assessment system for energy efficiency and define major characteristics and eight technological directions for building green 5G target networks. These suggestions will be key to helping carriers achieve their strategic carbon goals while evolving their networks.

We suggest energy efficiency (E^2) as the basis for assessing network energy efficiency.

High device integration, site simplification, intelligence, and full-lifecycle environmental friendliness are the four major characteristics of green networks.

In addition to these, eight technological directions will help guide operators developing green networks.

03 Energy Efficiency: Basis of Green 5G Networks

Energy Efficiency Assessment Spans Across a Network's Lifecycle

Appropriate systems for indicating a network's energy performance and reasonable energy efficiency objectives should be set up during planning and construction to meet the evolution and green requirements. All technologies and solutions should also be planned and deployed to support these objectives.

Energy efficiency assessment during network operations and optimization helps operators better understand their networks and identify weak points in energy efficiency. This will help operators target the reconfigurations required to enhance their energy-saving deployments.

During network upgrade and reconstruction, once the areas with the lowest energy efficiency are recognized and the causes are found out, operators will better understand the potential for energy saving on their networks and will be able to find the exact solutions needed to upgrade or reconstruct their networks.

Multi-Dimensional Comprehensive Assessment

The key to assessment is to find appropriate indicators to describe a network's energy performance. Traditionally, energy efficiency is defined as the effective output of per unit energy usage. However, in the real world, traffic volume is used to evaluate the energy efficiency. That is, energy efficiency is measured based on the ratio of traffic volume to the energy used. This is generally referred to as traffic energy efficiency.

Ample research has been conducted and practices explored for using traffic energy efficiency to analyze and improve network energy efficiency.

New services and scenarios are emerging along with the development of networks, with each having different requirements on data rates. This requires operators to focus on not just growing traffic demand but also service experience.

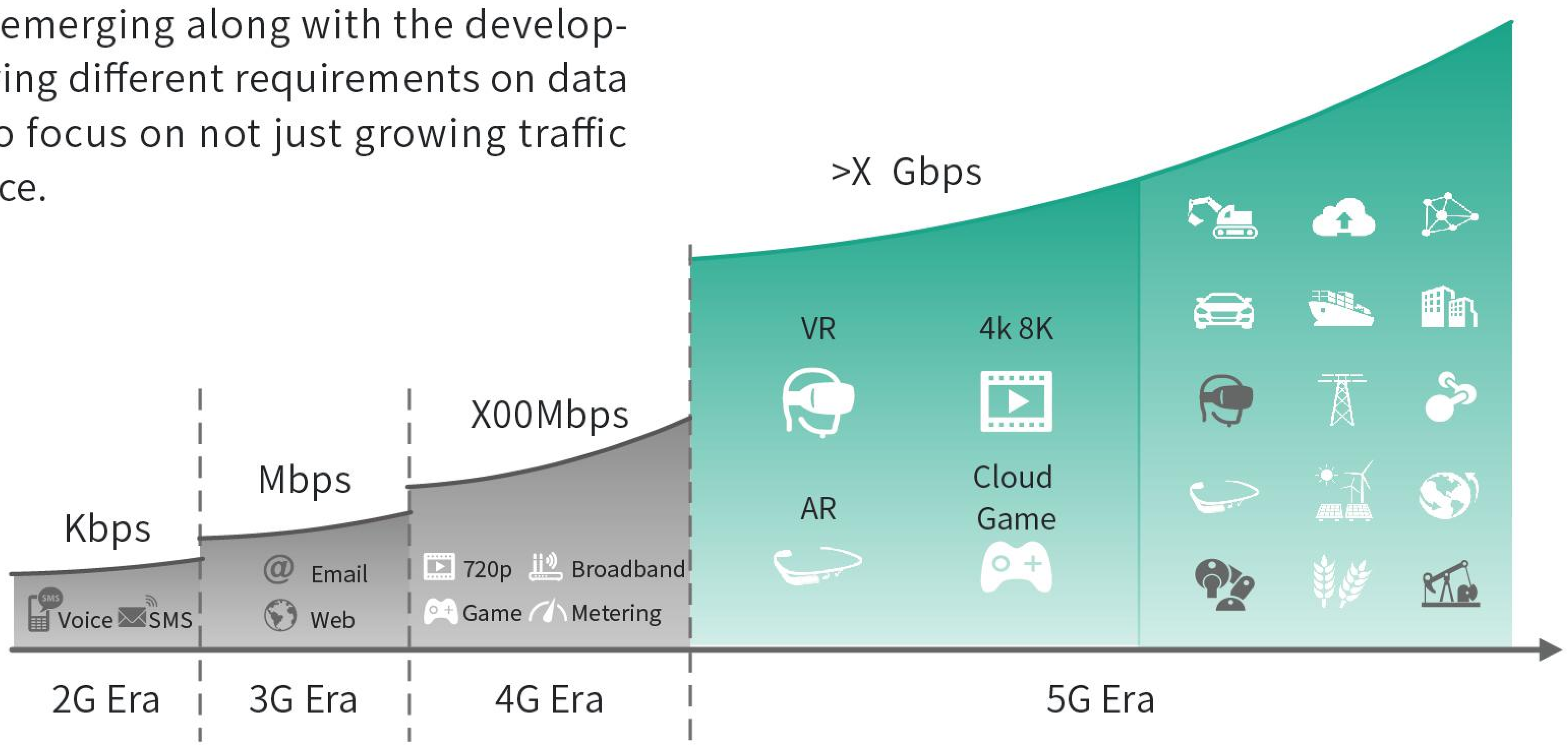


Figure 1 Data rates of different services

In partnership with operators, we have analyzed the energy efficiency of mobile networks in many areas around the globe. One of our key findings is that users perceived vastly different data rates from some networks even with a close level of energy efficiency.

This shows that traffic energy efficiency, focusing on traffic volume, cannot precisely reflect the quality of services.

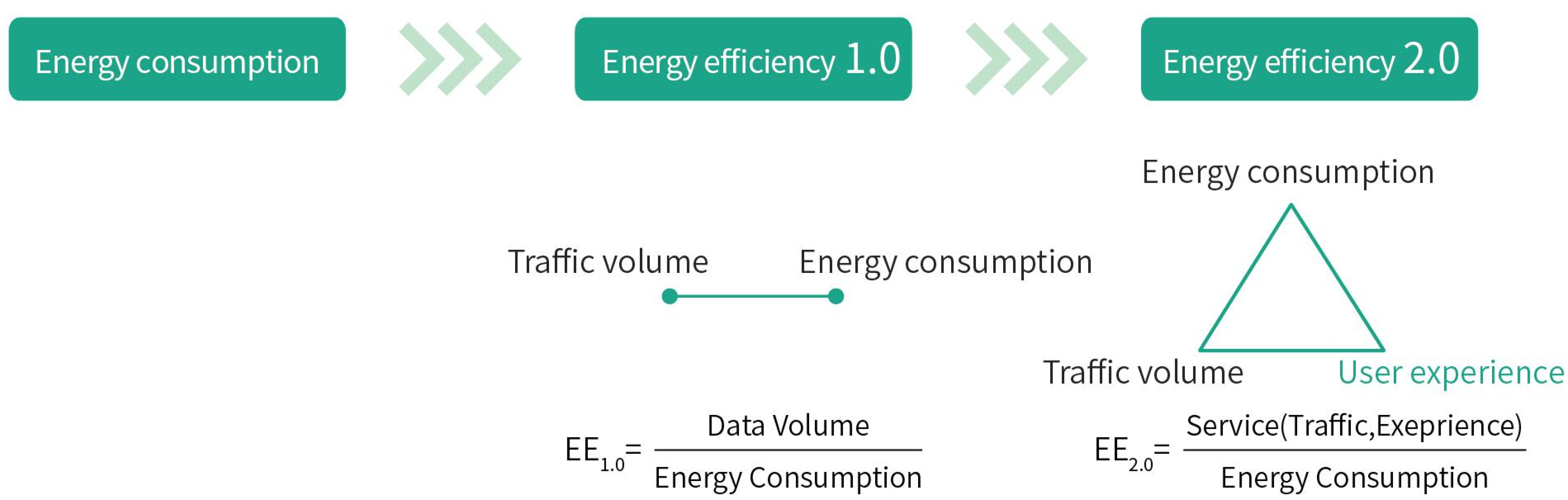
Table 1 Traffic energy efficiency with different user-perceived rates

Network	Traffic Energy Efficiency (GB/kWh)	DL User-Perceived Rate (Mbps)
A	6.4	6.3
B	6.2	9.6
C	6.7	20.1

Therefore, the evaluation system needs to improve. We cannot rely simply on traffic volume and must expand to more dimensions, such as both traffic volumes and user experience.

A more comprehensive evaluation system will help operators evaluate network energy efficiency more appropriately based on development stages and scenario-specific service priorities. In this way, their mobile networks will be able to handle more data traffic while consuming less energy and improving user experience.

Figure 2 Changing evaluation of energy efficiency as networks develop



New types of services, such as URLLC[2] and mMTC[3], and new scenarios, such as network slicing, are developing.

Category-based Objective Evaluation

There are both objective and subjective factors affecting energy efficiency. The objective factors include population density, weather conditions, and geographic environments, and the subjective factors refer to construction standards, architecture, hardware configuration, and feature deployment. To minimize the impact of objective factors on evaluation, they should be normalized in advance or classified so that category-based objective evaluation will be possible to recognize weaknesses more precisely and create conditions for better evaluation results.

For example, operators classify their networks first based on population density and then further divide the areas of a network based on site spacing before evaluation. As such, the networks in urban areas that have small site spacing are evaluated as one category, while the rural networks with a large spacing are evaluated as another category.

Dynamic Changes of Network Energy Efficiency

Network energy efficiency tends to fluctuate vastly during peak hours and off-peak hours. In high-traffic hours, traffic energy efficiency is high, but the user-perceived rate might be quite low, and the opposite will be true in hours with low traffic.

Network energy efficiency is also likely to differ as a network develops at different stages. In the early days, the traffic energy efficiency generally stays at a low level. Later on, with growing traffic volume, the traffic energy efficiency gradually increases.

Key Factors Affecting Network Energy Efficiency

The following are generalized categories of factors that affect network energy efficiency.

Networking architecture: such as the proportions of centralized equipment rooms and outdoor equipment rooms and band-varying spectrum policies.

Device efficiency: frequencies at which hardware is replaced, ultra-broadband and high-integration devices, and energy-saving features.。

Radio performance: interference and spectral efficiency and the use of high-gain antennas.

Services and loads: traffic demand, camping ratio of 5G UEs, and service types and distribution.

The key factors may differ depending on the scenario and area. Therefore, network energy efficiency requires area-specific evaluation to ensure accurate results.

04 Major Characteristics of Green 5G Networks

As networks have developed from GSM to what they are today, new technologies have constantly developed to boost spectral efficiency and network performance. At the same time, networks have also improved in terms of energy efficiency, contributing to a constantly decreasing OPEX[4].

4.1 High Integration of Devices

Fueled by continuous progress in basic sciences and other related disciplines, radio devices have improved significantly, enabling multiple bands and radio access technologies to be deployed on just a single module. As opposed to deploying one band of only one radio access technology on a single module, the new capability allows operators to provide services through multiple bands and radio standards in one network. Such convergence minimizes the number of devices deployed, simplifies site construction, relaxes site deployment requirements, facilitates network evolution, and makes operations more efficient, bringing down the energy consumption of mobile networks.

Figure 3 Pooling progress in basic sciences and other disciplines into radio devices

As more bands are introduced to mobile networks, the level of device integration needs to be further increased so that a single module can provide as many services as possible.

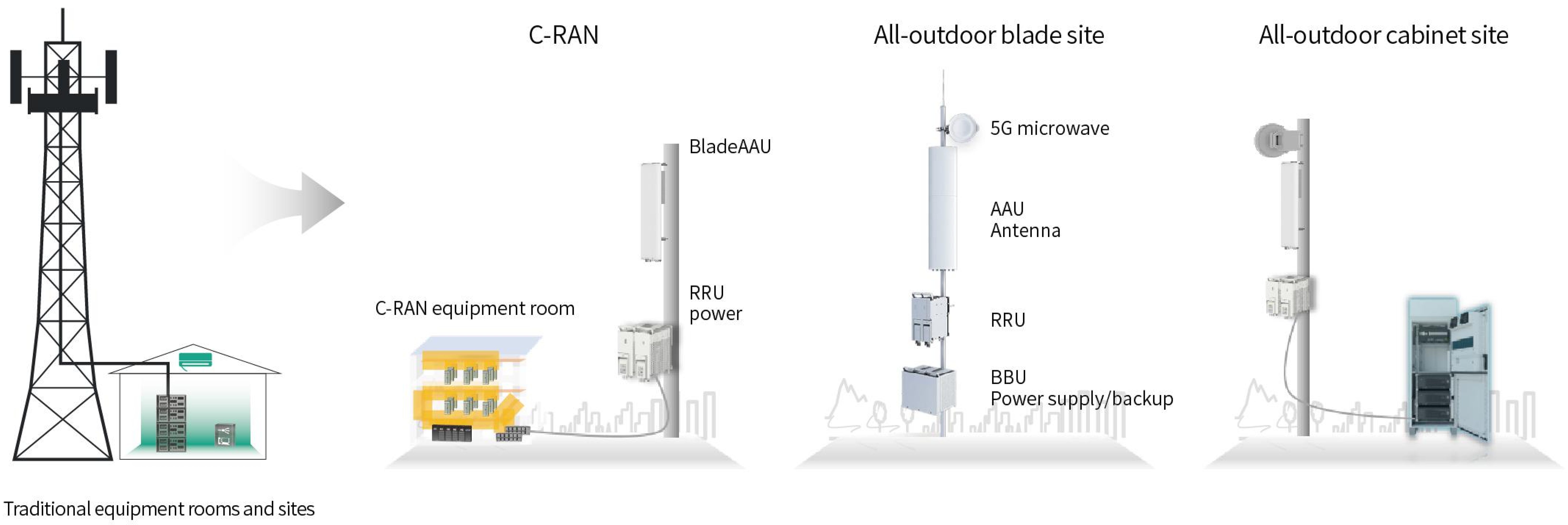
Figure 4 Increasing integration of radio devices

4.2 Site Simplification

An information flow cycle involves terminals, air interfaces, AAU[5]/RRU[6] main equipment, BBU[7], transport networks, and core networks. Therefore, higher efficiency of information flows and less energy consumed by other devices and components will both help reduce site-level energy consumption.

Site simplification aims to reduce the energy consumed by other devices. In a traditional D-RAN[8] site, each physical site uses an equipment room, each requiring air conditioning. This leads to considerable energy consumption and it is not productive. With sites simplified, operators need fewer equipment rooms and air conditioners, and power supply and transmission deployments are streamlined, helping boosting the overall efficiency at sites.

Figure 5 Simplified site



Site simplification primarily means simplified site construction. As traditional equipment rooms are replaced by cabinets and blade power supplies are used, site footprint is downsized by a huge margin to drastically decrease wasted energy. Based on China Tower's statistics, after three cabinets were integrated into a single one in China's southwest Guizhou province, the rent and electricity bills reduced by CNY4,400 per month, cutting O&M costs by 75%. Blade power supply modules were deployed in Beijing and Langfang, improving site energy efficiency to 96% and reducing 700 kWh of cooling per year. They also saw a 50% reduction in the heat loss over cables.

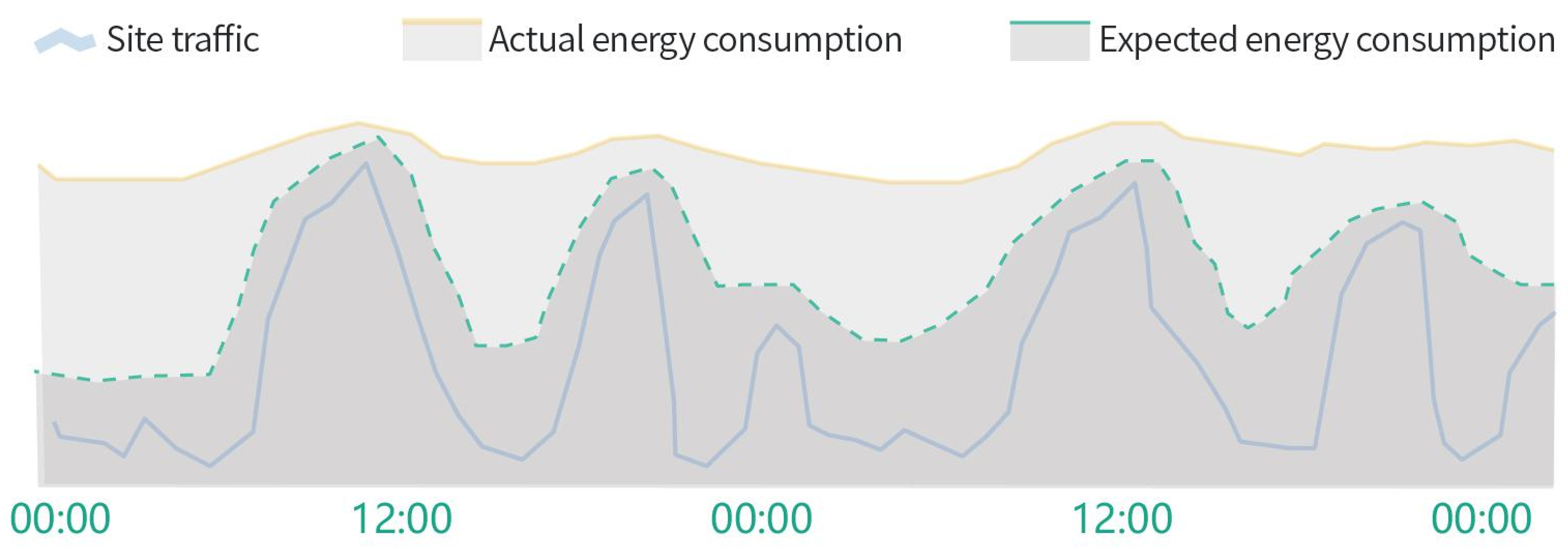
Site simplification also means streamlined power supply. AC/DC integrated power supply, multiple output modes in one module, and linkage between power supply and energy storage systems will help streamline power supply.

Furthermore, site simplification covers simplified transmission. Indoor transport modules are replaced by outdoor ones to facilitate all-outdoor simplified site deployment.

4.3 Network Intelligence

Network energy efficiency changes with service traffic as it enters peak and off-peak periods in a day. Software adjustment is the key to improving energy efficiency of off-peak hours by putting resources — such as carriers, channels, and symbols — to sleep and tweaking transmit power. Operators have long shown mixed attitudes towards software-based energy saving solutions: excited at their potential for diminishing network energy usage but also showing great concern for their negative impact on network performance.

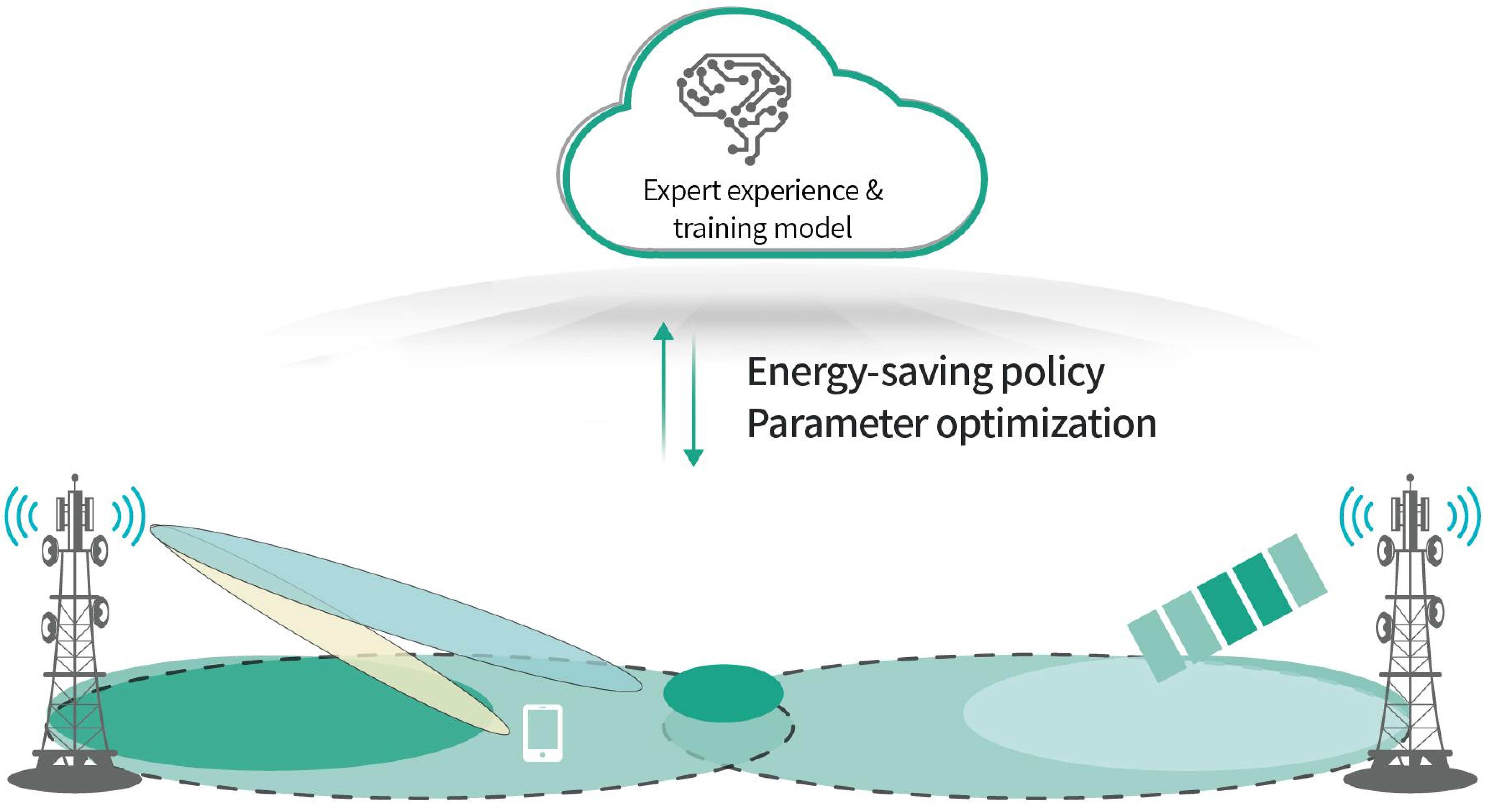
Figure 6 Energy efficiency comparison between peak and off-peak hours



Network intelligence enables manual solutions to be replaced with AI-powered automation, enabling traffic forecast, KPI[9] and energy-saving optimization, and energy-saving effect prediction. With AI, sleeping resources are woken up immediately upon a traffic surge, and sleeping policies are adjusted in response to changing network performance requirements.

Network intelligence aims to maximize both energy-saving and network performance.

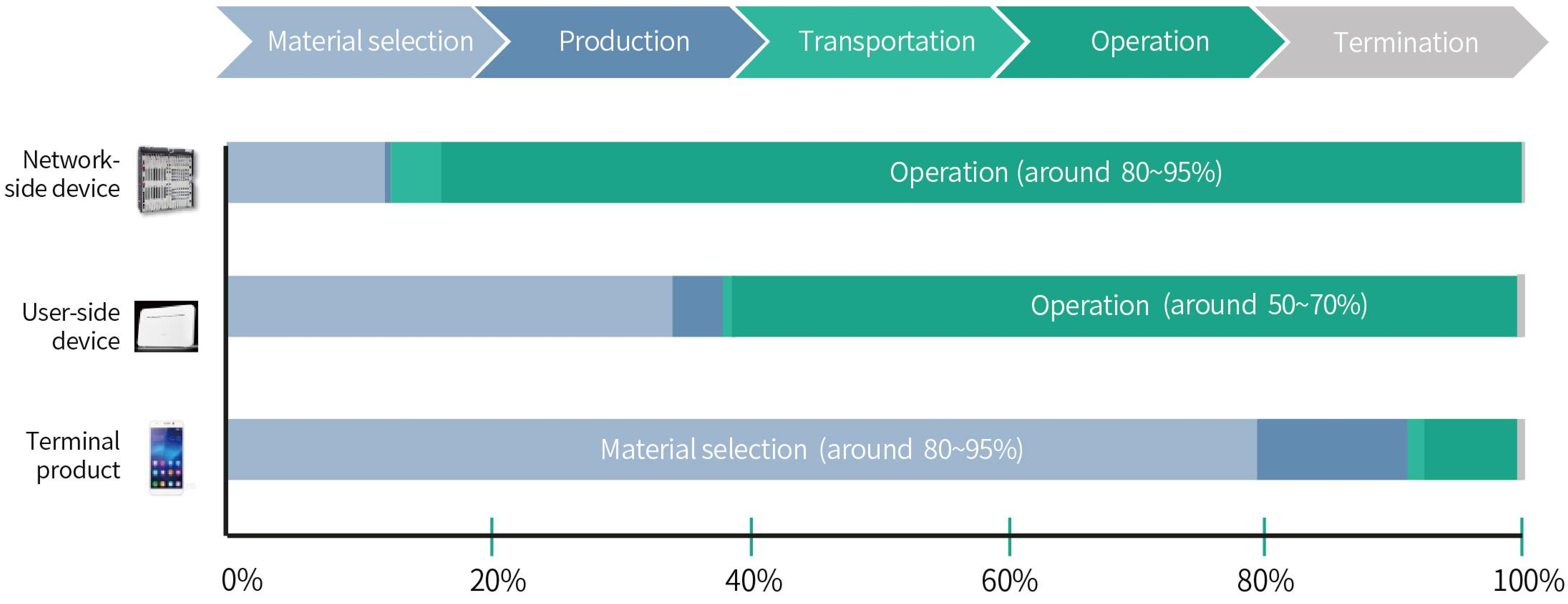
Figure 7 AI-based power saving



4.4 Full-Lifecycle Environment-Friendliness

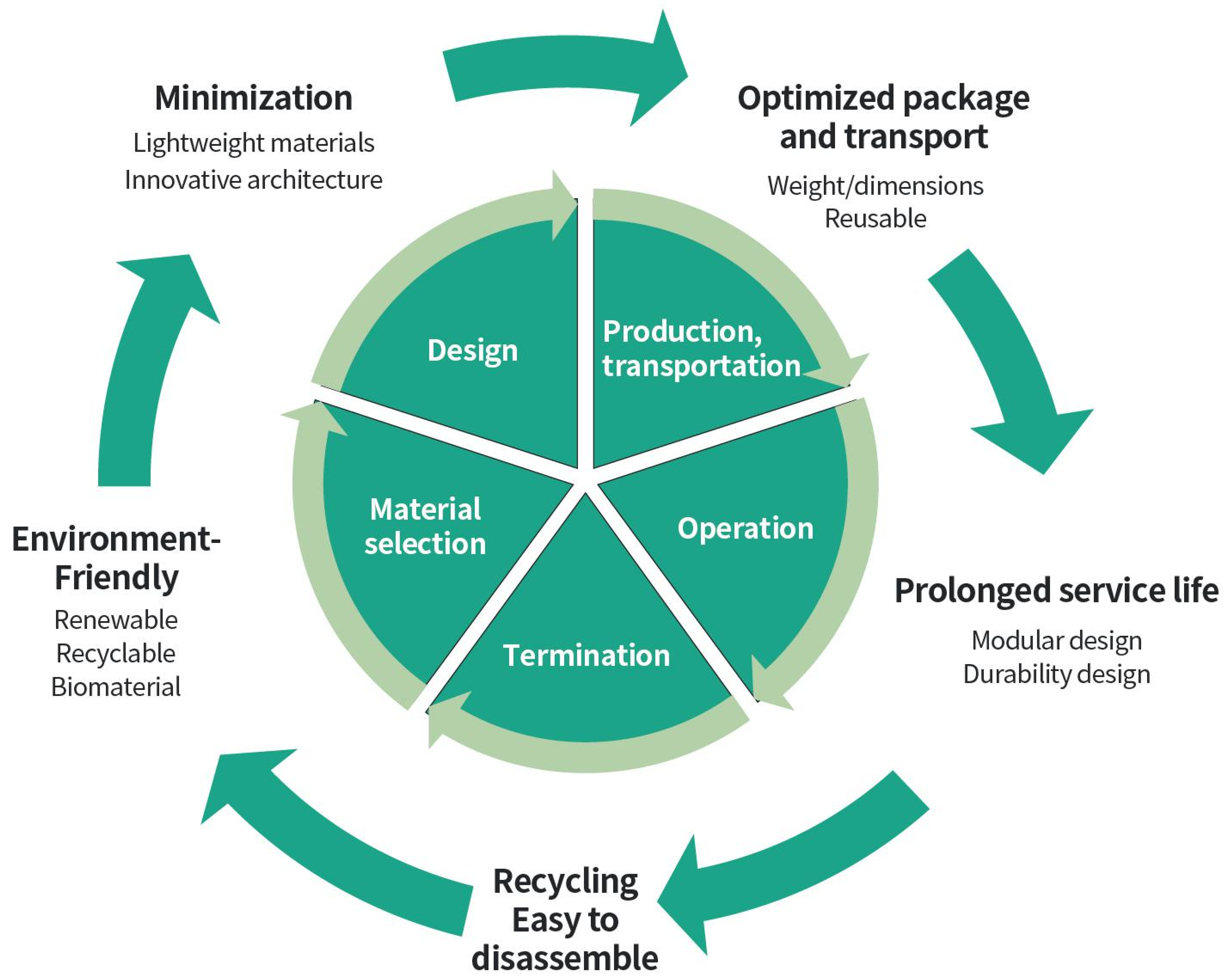
A product lifecycle includes material selection, design, production, transportation, operation, and termination.

Figure 8 Carbon emissions of different products at different stages of a lifecycle



Recycling-oriented product lifecycle management helps the industry minimize its dependence on natural resources by selecting environment-friendly materials, using waste-minimization product design, optimizing packaging and transportation, maximally prolonging service life, and using recyclable and easy-to-disassemble design.

Figure 9 Recycling-oriented product lifecycle management



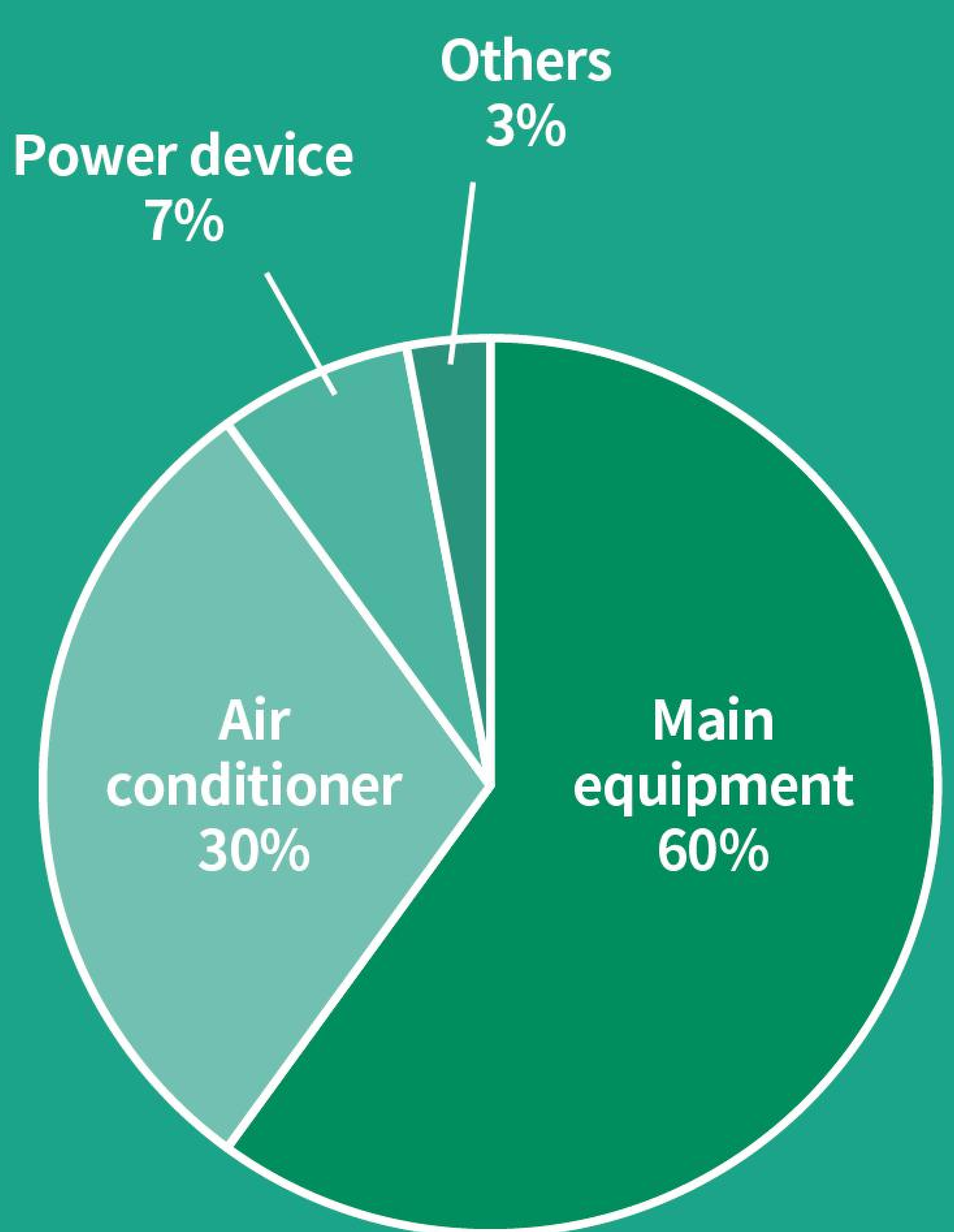
05 Eight Directions: Technical Development Trends of Green 5G Networks

In addition to standards for measuring green networks and major features that can characterize them, technical directions are essential if operators are to develop green 5G networks.

Direction 1: Multi-Antenna RF Reduces Per-Bit Energy Consumption and Increases Transmission Efficiency

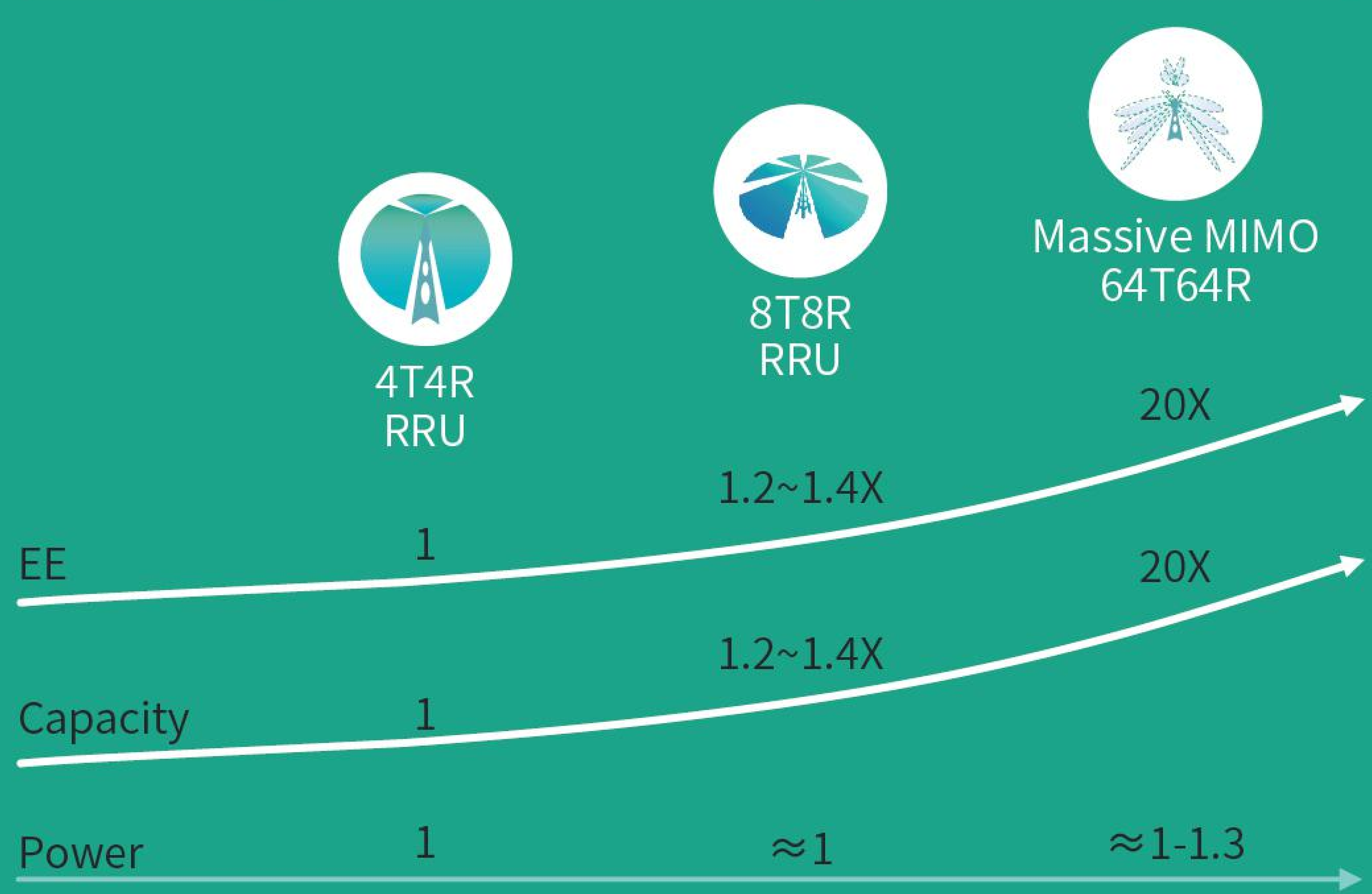
RF devices account for approximately 60% of the total energy consumption of a wireless network site. Reducing this consumption is the key to developing green 5G networks.

Figure 10 Site energy consumption composition



Multi-antenna evolution, from 1T2R, 2T4R, 4R4R, and 8T8R RF modules to 64T64R AAUs that are widely used on 5G networks, greatly improves per-bit energy efficiency.

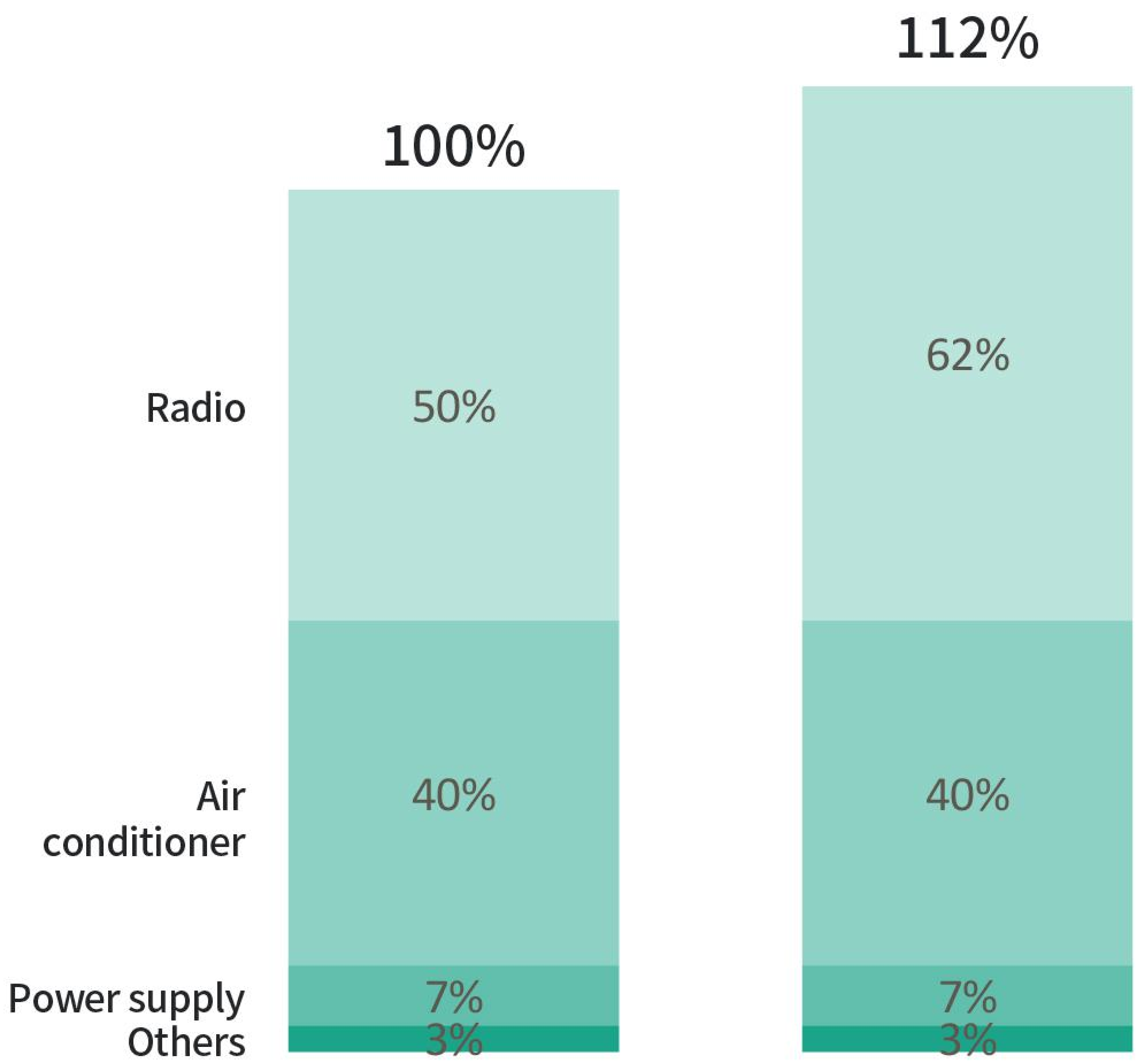
Figure 11 Energy efficiency improvement brought by multi-antenna technology



AAU uses a multi-antenna and multi-channel architecture, leveraging spatial multiplexing to significantly boost system capacity. Signal phases and amplitudes can also be tweaked to concentrate radio energy on narrower beams that point to users more precisely, increasing energy transmission efficiency and greatly raising per-bit energy efficiency. In addition, we have been taking constant measures, such as by developing multi-disciplinary convergent innovation and improving power amplifier efficiency, to reduce absolute energy consumption. As networks continue to develop, this huge potential for system capacity will justify the AAU as an essential tool for operators to meet continuously growing traffic demand from individual and industrial users.

With radio access technologies and bandwidth capabilities increasing, the total radio transmit power of base stations has been growing. However, increasing transmit power goes against energy-saving objectives.

Figure 12 A 1-dB increase in base station transmit power leads to an approximate 10% increase in base station power consumption



Improving energy transmission efficiency is the new track for AAU energy saving development. The ultra-large antenna array — a new innovation created by combining progress in software and hardware, including new baseband algorithms and antennas — has been adopted to maximize the potential of antennas for energy saving and guarantee both better experience and coverage. Theoretically, AAU products using the ultra-large antenna array consume 30% less electricity while delivering the same level of coverage and experience for users in cell-edge areas.

Figure 13 New direction for AAU energy saving

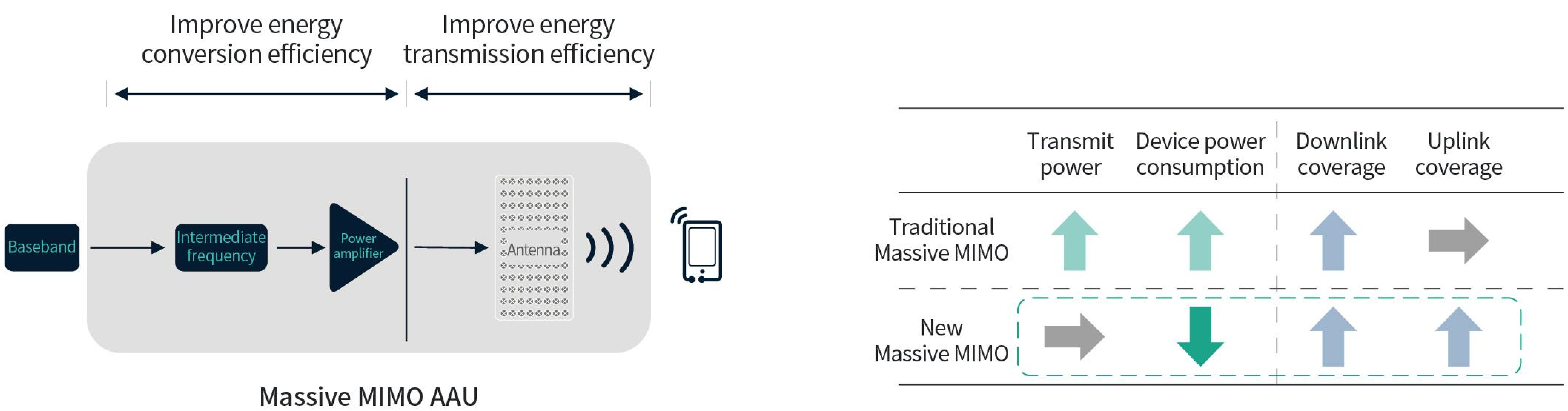
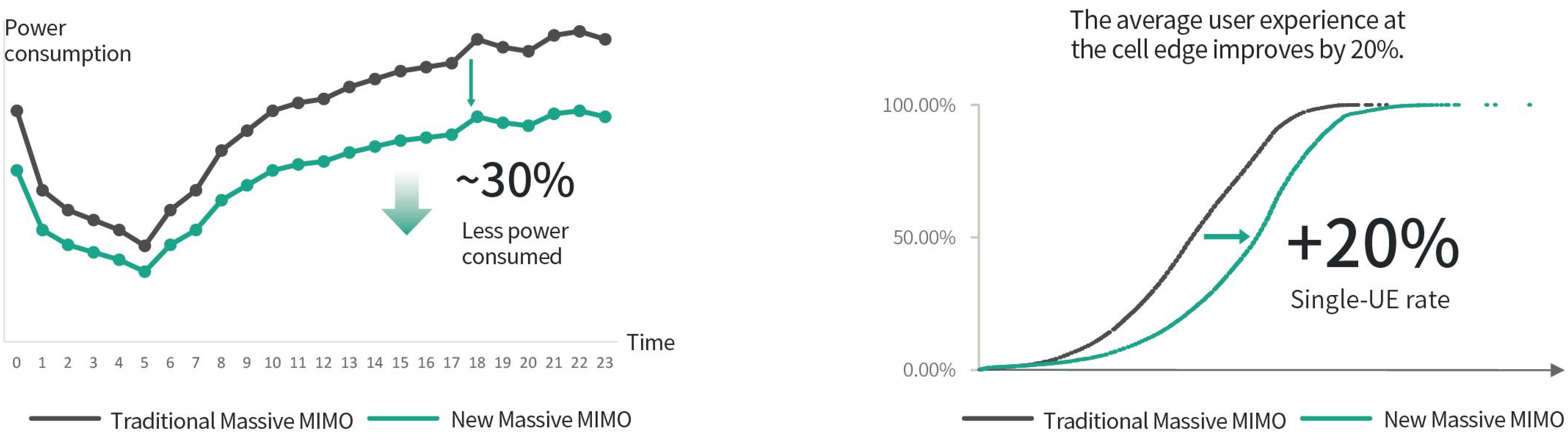


Figure 14 Energy-saving benefits of ultra-large antenna array

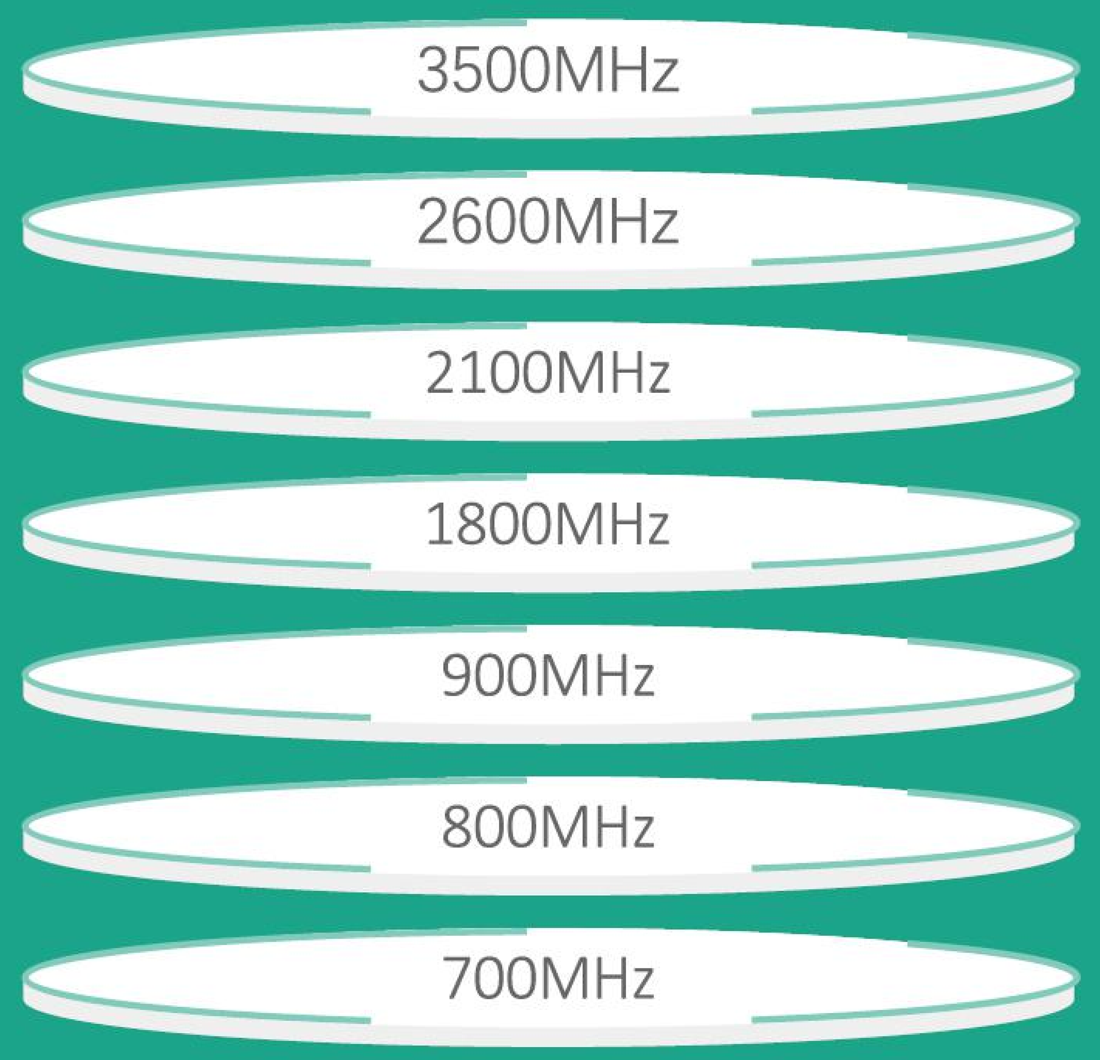


Direction 2: Ultra-Wideband Devices ReduceEnergy Consumption

More bands imply more complex antenna installation. Power consumption will rise as a result, creating a tough challenge.

As networks develop, more bands are used, leading to more RF modules at a site and higher power consumption at the site.

Figure 15 Operators' spectrum resources



Ultra-broadband and simple antenna deployment allow for more bands on one RF module without incurring additional energy usage.

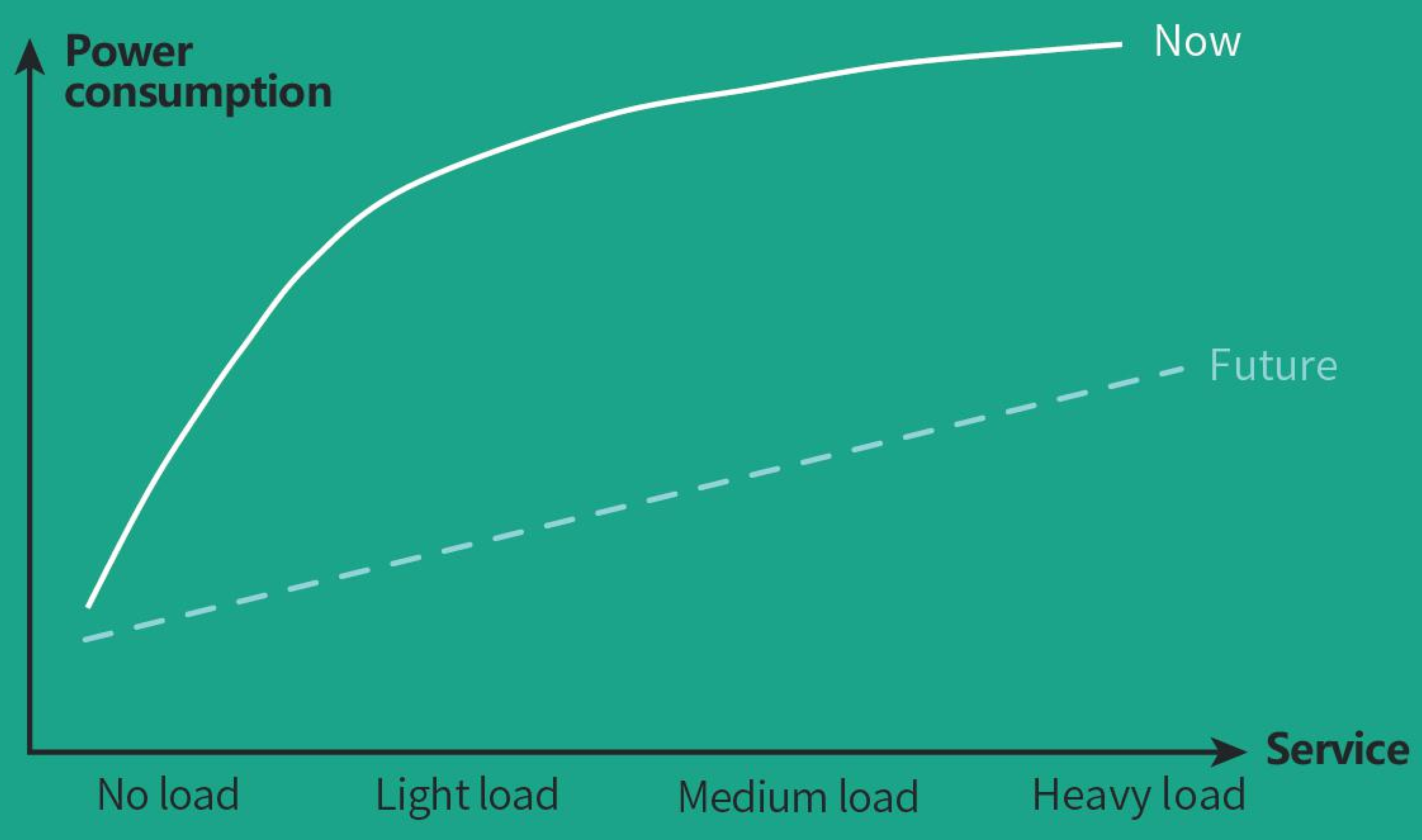
Higher integration enables a device module to expand its RF capability from just a single band to several bands and provide an ultra-large bandwidth. This is important as it transforms site construction from deployment of just one band on one RRU or AAU module to one integrated module that supports multiple bands. For operators, the benefit is that one module can be used to provide various services that previously required multiple modules to implement, helping lower costs. More importantly, significantly fewer modules are needed, bringing down overall energy consumption.

Take the six bands 700 MHz, 800 MHz, 900 MHz, 1800 MHz, 2100 MHz, and 2600 MHz as an example. Each sector requires six RRUs or AAUs on a traditional base station, whereas only two RRUs/AAUs are required in the ultra-broadband solution, with one for the 700–900 MHz bands and the other for 1800–2600 MHz bands.

One of our customers in the Netherlands once deployed two RF modules to provide services on the 800 MHz and 900 MHz bands. But now they use only one ultra-broadband RF module to provide services on the 700 MHz, 800 MHz, and 900 MHz bands with essentially the same level of power consumption. The increased integration of RF modules helps it achieve band expansion without incurring additional energy usage.

Direction 3: Near-Linear Power Usage Changes Due to Enhanced Hardware to Reduce Medium- and Low-Load Energy Consumption

Figure 16 Non-linear hardware efficiency change with varying load levels



Currently, RF hardware transmits with a higher efficiency as traffic loads increase and tends to output with a lower one as the traffic loads decrease. Some components are always in working mode and cannot automatically adjust their status based on the load change.

On the premise that reliability is guaranteed, hardware components, such as intermediate frequency and baseband parts, are designed to work in standby, sleep, or working modes based on the dynamic change of traffic load. More components can be adjusted to work in sleep mode, while the adjustment time is shortened. As such, the hardware power consumption changes nearly in direct proportion with load levels.

The energy consumption of a power amplifier (PA) largely contributes to the total power consumption of RF hardware. We continuously improve its efficiency in medium-load and light-load scenarios.

The deployment by operators in China has demonstrated that deep dormancy helps reduce power consumption by more than 60% in networks under a light load.

Direction 4: Simplified Sites Without Equipment Rooms and Air Conditioners

There are a large number of D-RAN sites around the world. The energy consumption of air conditioners in equipment rooms accounts for approximately 40% of the site's total energy consumption, dragging down the overall site energy efficiency to a low level.

- With centralized BBU deployment, one air conditioner can be used for the cooling of multiple sites rather than one for each as is the case in separate BBU deployment. To further save electricity, liquid-based and other natural cooling methods are good options for equipment rooms. Studies in China have shown that 17,000 kWh of electricity can be saved at a single site each year with centralized BBU deployment.

- "One site, one cabinet" and "blade site deployment" can be used as an alternative to one air conditioner at each site. With "one site, one cabinet", cooling media works in close proximity to heat-producing devices, facilitating precise and targeted cooling to slash energy consumption. "Blade site deployment" focuses on saving energy by mounting devices on poles — a deployment mode that can maximize the effect of natural cooling to help remove air conditioners from sites. This will allow a 60% to 97% increase in energy efficiency on sites.

Figure 17 "One site, one cabinet" deployment in China

Figure 18 "Blade site" deployment in China

Direction 5: Linked Site Energy Improves Comprehensive Energy Efficiency

Traditionally, power supply, power storage, and power usage components at a site are unable to sense and collaborate with one another or sense current service loads and running status. As a result, end-to-end power supply and backup efficiency is low, which greatly increases the site's power consumption level.

These components are now linked so that they can collaborate to adjust temperature and power operations in line with service loads, thereby reducing energy waste. For operators, this will help them better fulfill site energy saving targets.

Clean energy has been gradually and efficiently introduced. Traditional sites are mainly powered by mains power or diesel generators. In the future, power sources will be more diversified and cleaner. New energy, especially solar power, will be gradually incorporated into site power supply. Linking services to solar energy and mains power will enable PV panels to work at the highest efficiency and offer diversified optimal power supply solutions.

The temperature in equipment rooms is adjusted based on service status and device capability. A 10° C increase in the temperature of an equipment room means a 20% decrease in the power consumption of that room.

Power modules and backup power can be adaptively adjusted based on the predictions of power consumption and battery state of charge (SOC)/state of health (SOH)to achieve optimal staggered usage of mains electricity, thereby saving on electricity costs. The intelligent staggering has already been implemented in Zhejiang, China, where it has helped the operator cut 17.1% electricity fees per site every year.

Figure 19 Solar power supply in Greece

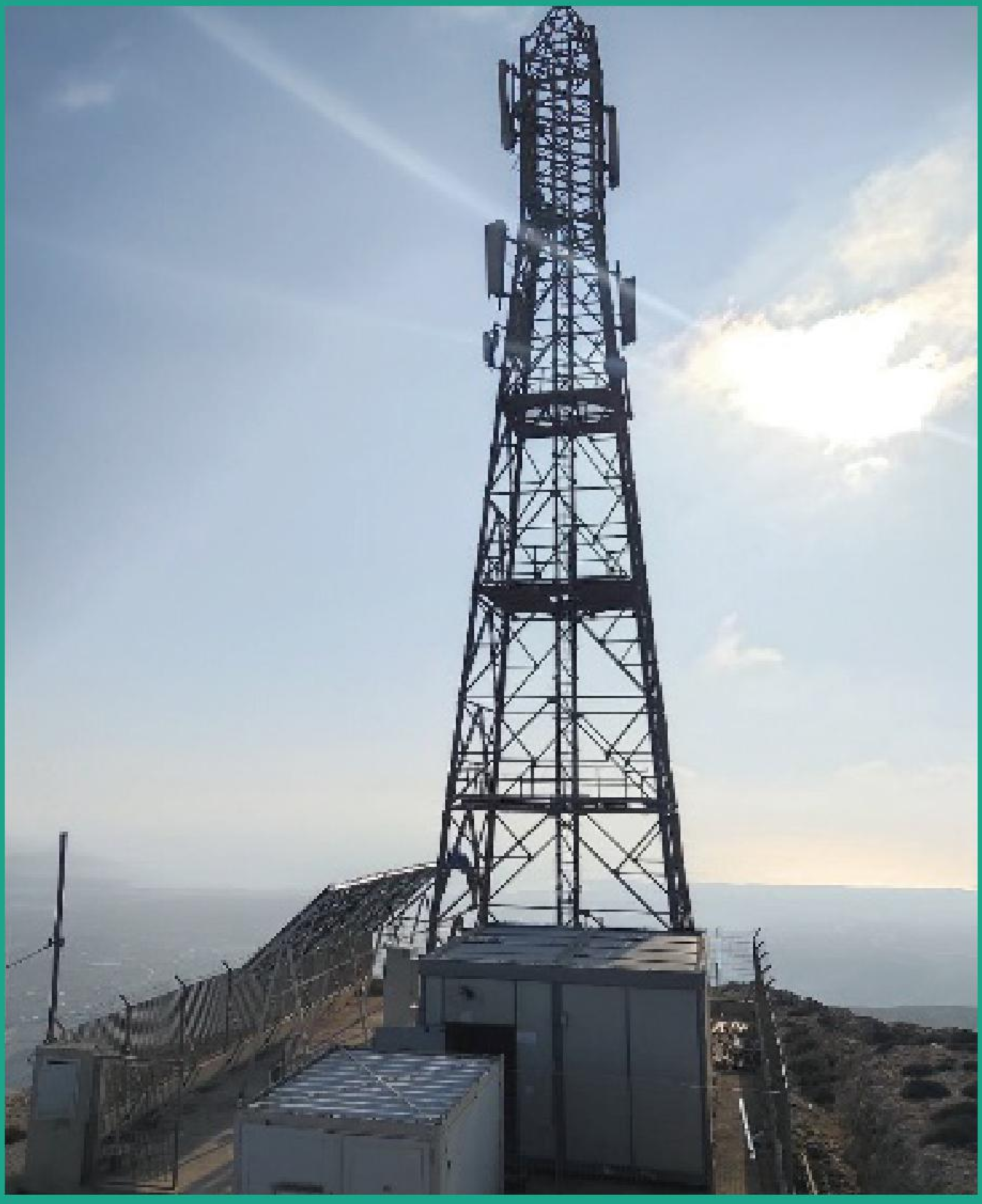


Figure 20 Replacement of diesel generators with PV power in Pakistan

Based on our cases in Greece, solar power can reduce an operator's mains power consumption by 51.2%, saving 14,500 kWh of electricity per year.

In Pakistan, the application of PV and linking technologies significantly cuts the operating time of diesel generators, reducing the OPEX by 81% annually.

Direction 6: Intelligence for Energy Saving and Network Performance

Operators usually power off some active hardware when cells are lightly loaded to reduce power consumption. In the past, there were two energy-saving mechanisms for operators: carrier-level shutdown and channel-level shutdown. That is, some carriers or RF channels are shut down at a fixed time or when the load is below a certain threshold, thereby reducing the power consumption of equipment.

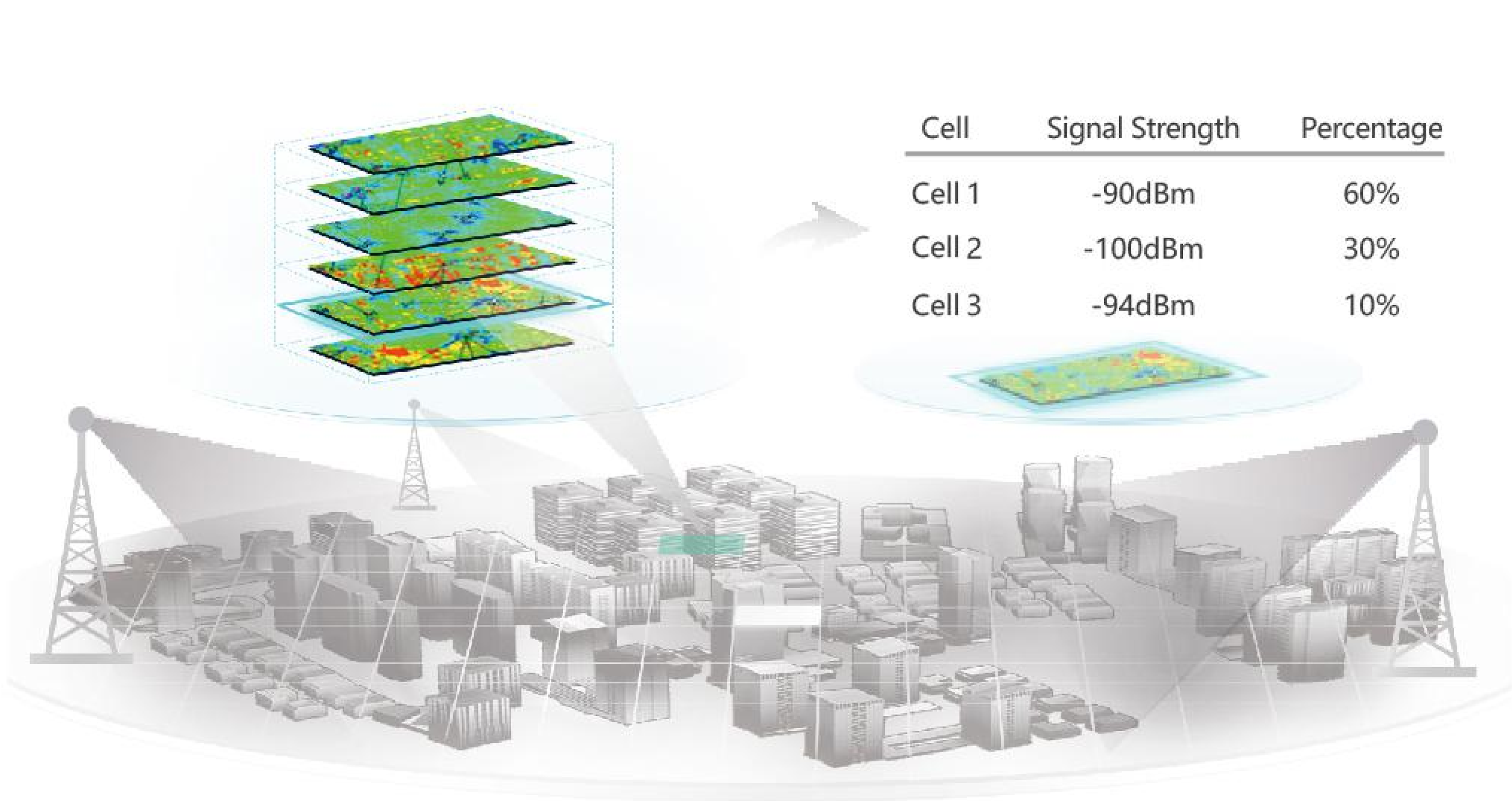
However, mobile networks employ multiple radio access technologies and multiple bands. Coverage of multiple sites and cells may overlap. Coverage scenarios and service characteristics are different among cells. Therefore, shutdown thresholds need to be set and managed independently for each site and each cell. Otherwise, network quality and user experience cannot be ensured.

Network energy saving solutions are becoming more intelligent. AI technologies are used to calculate shutdown thresholds and allocate network and spectrum resources in real time based on network mode, band, scenario, service characteristics, and network running status. In this way, the best energy saving solution can be employed, while still retaining optimal network performance.

AI-based power saving solution:

- Accurate co-coverage analysis identifies more cells for power saving

Figure 21 More cells for power saving after accurate co-coverage analysis



- Multi-band multi-RAT coordination enables cooperative energy saving on the entire network
- Optimal service allocation is achieved based on carrier-level energy efficiency
- Parameter optimization is activated to achieve the optimal trade-off between energy saving and network performance

- Dynamic shutdown is implemented based on historical service load characteristics

Figure 22 Traffic volume forecast based on historical traffic characteristics

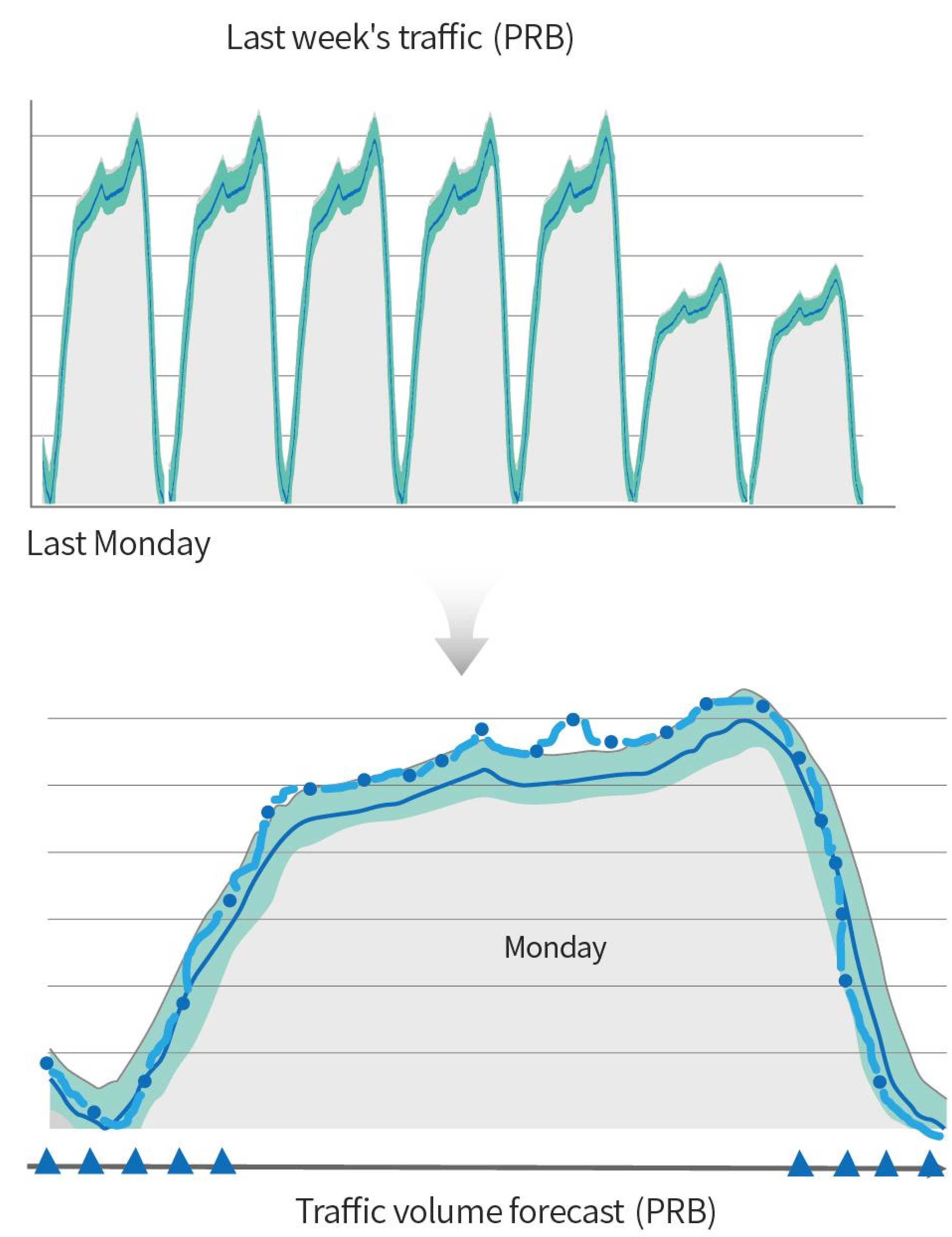


Figure 23 Service and network performance assurance

· Energy saving benefits are estimated to formulate the optimal deployment solution.

The intelligent network has been put into practice in Changsha, China. An intelligent network reduces its energy consumption by more than 25% while retaining network performance. The continuous development of intelligent networks means that energy consumption will also be on a constant downward trend.

Direction 7: Switching to 5G to Maximize Its Advantages in Energy Efficiency

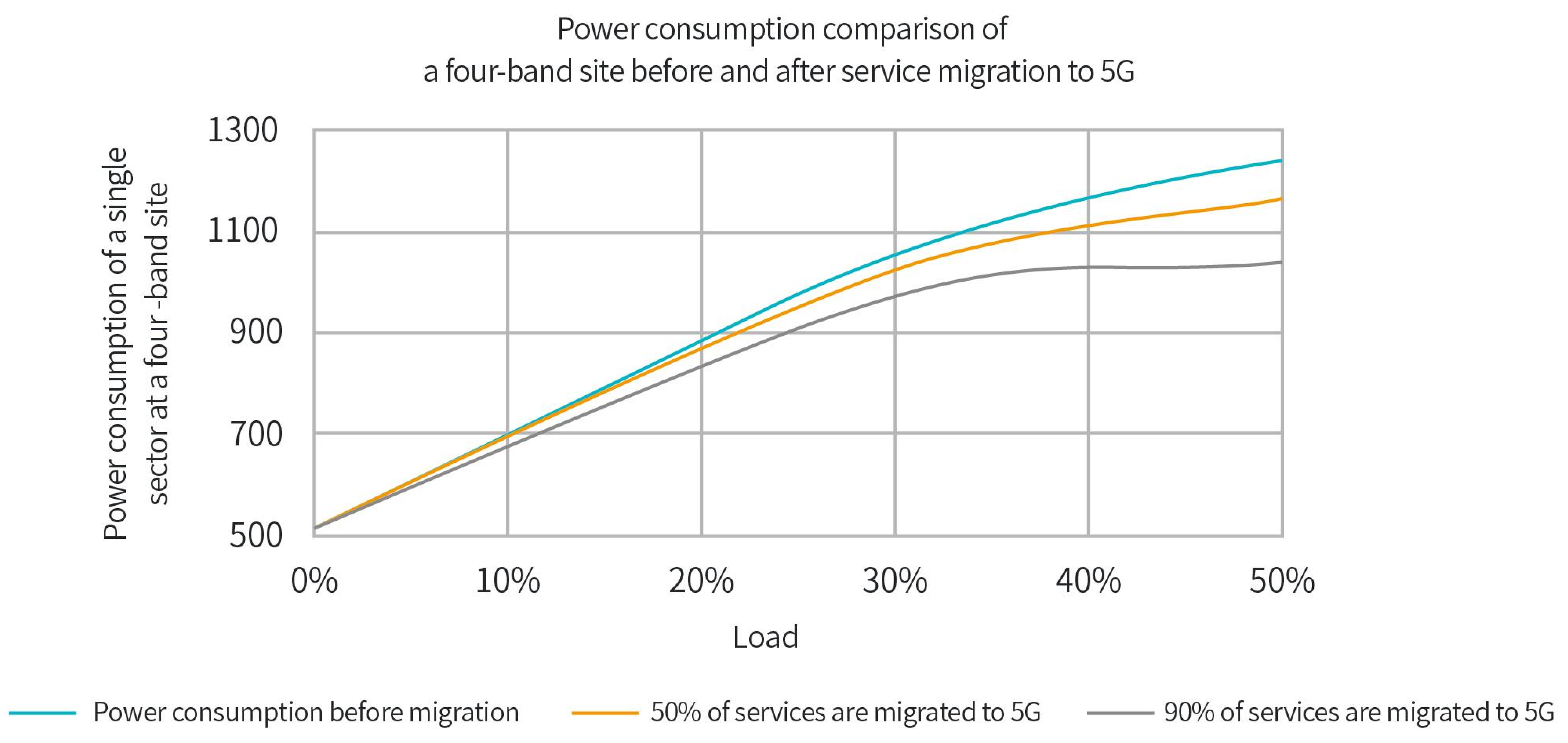
4G is seven to ten times more energy-efficient than 3G, while 5G is 20 times more energy-efficient than 4G.

1. 5G protocols are more conducive to energy saving. For example, there is no CRS, the period of common signals can be adjusted, and UE-level power control is supported. The spectral efficiency of 5G is higher than LTE and will be continuously improved upon in the future.
2. 5G uses better coding schemes and polar codes to help reduce energy consumption.
3. Massive MIMO beamforming effectively improves the signal-to-noise ratio (SNR) and energy efficiency.
4. Thanks to a wider bandwidth and better spectral efficiency, data transmitted per unit time in 5G is 10 times more than LTE, lowering per-bit power consumption.

After services are migrated to 5G, the energy efficiency of the entire network is improved and energy consumption is reduced.

The more services migrated, the more significant the decrease in power consumption.

Figure 24 Relationship between network power consumption and service migration



Moreover, existing bands can be effectively refarmed for 5G after services are migrated to 5G to maximize its value.

5G network use cases in multiple places show that the continuous introduction of new 5G technologies drives the improvement of network energy efficiency. Exponential traffic growth that will be brought on by AR[10]/VR[11], smart factories, smart cities and other applications is inevitable, meaning that service migration to 5G will tap into its full potential for energy efficiency and minimize network energy consumption.

Direction 8: Full-Lifecycle Recycling Reduces Dependence on Natural Resources

The life cycle of ICT products, including design, production, manufacturing, and use, involves energy consumption and carbon emissions. The recycling philosophy should be incorporated into product lifecycle management to minimize the dependence on natural resources and realize a low-carbon product lifecycle.

During manufacturing and transportation, environmentally friendly materials are used. Waste minimization design as well as packaging and transportation optimization is leveraged to reduce resource consumption. The service life of a product is extended through modularization and durability design. Recyclable materials and easy-to-disassemble design make recycling easier, further reducing resource consumption and lessening the dependence on natural resources.

Figure 25 Light-weight recyclable plastic steel pallet

06 Vision of Wireless Networks 2030

5G is ushering in an era of wireless communications that transform a wide range of industries at unprecedented depth and breadth. The commercial use of 5G is already spreading rapidly around the world, further improving communication capabilities and expanding not only the "human connection" but also the "physical connection" between terminals in a wide range of industries. It not only better connects people, but also establishes "IoT" among terminals of various industries, marking the transformation of mobile communication from "connected people" to "connected everything". In the next decade, new services will emerge, such as immersive cloud XR, holographic communication, sensory interconnection, intelligent interaction, harmonized communication and sensing, native intelligence, digital twin, and all-domain coverage. This will drive wireless networks to move beyond human and physical connectivity to the smart connectivity of everything and bring about a hundredfold increase in network traffic demand.

To prevent mobile network power consumption from increasing linearly with the traffic, the energy efficiency of the network should also be improved a hundredfold to avoid watts from increasing with bits. To achieve this goal, we need to explore all-round energy-saving and carbon-reduction methods.

- **New air interface performance** continuous improvement of 5G/5.5G air interfaces, 6G air interfaces, THz ultra-bandwidth
- **New network architecture** air-to-ground integration, near-field coverage, on-demand delivery
- **New site forms** comprehensive energy supply integrated with wind and solar power, self-closed-loop energy/consumption
- **New hardware platform** new materials, new architecture, continuous improvement of PA efficiency
- **New energy-saving technologies** dynamic linear shutdown, native AI

In the future, through the continued introduction of green design concepts and native AI optimization capabilities, we are committed to improving end-to-end energy efficiency by 100x while ensuring ultimate performance and experience. This will help assist the ICT infrastructure and terminal devices in consuming no more energy than 5G, contributing to sustainable human development as the core infrastructure of the digital economy.

Acronym and Abbreviation

No.	Acronym and Abbreviation	Full Name
1	FWA	Fixed Wireless Access
2	uRLLC	Ultra Reliable Low Latency Communication
3	mMTC	Massive Machine Type Communication
4	OPEX	Operating Expense
5	AAU	Active Antenna Unit
6	RRU	Remote Radio Unit
7	BBU	Baseband Unit
8	DRAN	Distributed RAN
9	KPI	Key Performance Indicator
10	AR	Augmented Reality
11	VR	Virtual Reality