International Telecommunication Union

ITU-T

TELECOMMUNICATION
STANDARDIZATION SECTOR
OF ITU

L.1390
(08/2022)

SERIES L: ENVIRONMENT AND ICTS, CLIMATE CHANGE, E-WASTE, ENERGY EFFICIENCY; CONSTRUCTION, INSTALLATION AND PROTECTION OF CABLES AND OTHER ELEMENTS OF OUTSIDE PLANT

Energy efficiency, smart energy and green data centres

Energy saving technologies and best practices for 5G radio access network (RAN) equipment

Recommendation ITU-T L.1390

ITU-T L-SERIES RECOMMENDATIONS

ENVIRONMENT AND ICTS, CLIMATE CHANGE, E-WASTE, ENERGY EFFICIENCY; CONSTRUCTION, INSTALLATION AND PROTECTION OF CABLES AND OTHER ELEMENTS OF OUTSIDE PLANT

OPTICAL FIBRE CABLES	
Cable structure and characteristics	L.100–L.124
Cable evaluation	L.125–L.149
Guidance and installation technique	L.150–L.199
OPTICAL INFRASTRUCTURES	
Infrastructure including node elements (except cables)	L.200–L.249
General aspects and network design	L.250–L.299
MAINTENANCE AND OPERATION	
Optical fibre cable maintenance	L.300–L.329
Infrastructure maintenance	L.330–L.349
Operation support and infrastructure management	L.350–L.379
Disaster management	L.380–L.399
PASSIVE OPTICAL DEVICES	L.400–L.429
MARINIZED TERRESTRIAL CABLES	L.430–L.449
E-WASTE AND CIRCULAR ECONOMY	L.1000–L.1199
POWER FEEDING AND ENERGY STORAGE	L.1200–L.1299
ENERGY EFFICIENCY, SMART ENERGY AND GREEN DATA CENTRES	**L.1300–L.1399**
ASSESSMENT METHODOLOGIES OF ICTS AND CO2 TRAJECTORIES	L.1400–L.1499
ADAPTATION TO CLIMATE CHANGE	L.1500–L.1599
CIRCULAR AND SUSTAINABLE CITIES AND COMMUNITIES	L.1600–L.1699
LOW COST SUSTAINABLE INFRASTRUCTURE	L.1700–L.1799

For further details, please refer to the list of ITU-T Recommendations.

Recommendation ITU-T L.1390

Energy saving technologies and best practices for 5G radio access network (RAN) equipment

Summary

The rapid development and commercialization of 5G radio communication technology is further accelerating 5G network construction. While it is an important enabler for the digitalization of other industries and thereby contributes to significant energy savings and emission reductions, it is also important to consider the energy consumption of the 5G network infrastructure itself.

Recommendation ITU-T L.1390 identifies energy saving potentials, describes energy saving principles and technologies for 5G RAN and related equipment, and provides best practice recommendations on when and how these technologies should be used and controlled, thereby reducing 5G RAN energy consumption, saving operational costs and making 5G RAN a green and high-efficiency network.

History

Edition	Recommendation	Approval	Study Group	Unique ID*
1.0	ITU-T L.1390	2022-08-13	5	11.1002/1000/15029

Keywords

5G, AI, best practice, energy saving, RAN.

* To access the Recommendation, type the URL http://handle.itu.int/ in the address field of your web browser, followed by the Recommendation's unique ID. For example, http://handle.itu.int/11.1002/1000/11830-en.

FOREWORD

The International Telecommunication Union (ITU) is the United Nations specialized agency in the field of telecommunications, information and communication technologies (ICTs). The ITU Telecommunication Standardization Sector (ITU-T) is a permanent organ of ITU. ITU-T is responsible for studying technical, operating and tariff questions and issuing Recommendations on them with a view to standardizing telecommunications on a worldwide basis.

The World Telecommunication Standardization Assembly (WTSA), which meets every four years, establishes the topics for study by the ITU-T study groups which, in turn, produce Recommendations on these topics.

The approval of ITU-T Recommendations is covered by the procedure laid down in WTSA Resolution 1.

In some areas of information technology which fall within ITU-T's purview, the necessary standards are prepared on a collaborative basis with ISO and IEC.

NOTE

In this Recommendation, the expression "Administration" is used for conciseness to indicate both a telecommunication administration and a recognized operating agency.

Compliance with this Recommendation is voluntary. However, the Recommendation may contain certain mandatory provisions (to ensure, e.g., interoperability or applicability) and compliance with the Recommendation is achieved when all of these mandatory provisions are met. The words "shall" or some other obligatory language such as "must" and the negative equivalents are used to express requirements. The use of such words does not suggest that compliance with the Recommendation is required of any party.

INTELLECTUAL PROPERTY RIGHTS

ITU draws attention to the possibility that the practice or implementation of this Recommendation may involve the use of a claimed Intellectual Property Right. ITU takes no position concerning the evidence, validity or applicability of claimed Intellectual Property Rights, whether asserted by ITU members or others outside of the Recommendation development process.

As of the date of approval of this Recommendation, ITU had not received notice of intellectual property, protected by patents/software copyrights, which may be required to implement this Recommendation. However, implementers are cautioned that this may not represent the latest information and are therefore strongly urged to consult the appropriate ITU-T databases available via the ITU-T website at http://www.itu.int/ITU-T/ipr/.

Table of Contents

Introduction

The rapid development and commercialization of 5G radio communication technology is further accelerating 5G network construction. While it is an important enabler for the digitalization of other industries and thereby contributes to significant energy savings and emission reductions [b-GeSI] [b-GSMA-1], it is also important to consider the energy consumption of the 5G network infrastructure itself. 5G will use wider bandwidths, more antennas and new frequency bands in order to boost the capacity of the mobile communication network and facilitate new use cases such as massive machine type communications (mMTC) and ultra-reliable low latency communications (uRLLC). Consequently, with the roll-out of 5G on top of existing network generations, network energy consumption will become an important operating cost for mobile network operators (MNOs).

Energy saving and emission reduction is not only the social responsibility of telecommunications operators but also inherent development needs of operators to continuously reduce electricity costs and improve market competitiveness. Hence, energy saving technologies and best practices for 5G RAN equipment are needed.

Recommendation ITU-T L.1390

Energy saving technologies and best practices for 5G radio access network (RAN) equipment

1 Scope

This Recommendation identifies energy saving potentials, describes energy saving principles and technologies for 5G RAN and related equipment, and provides best practice recommendations on when and how these technologies should be used and controlled to reduce 5G RAN energy consumption.

2 References

The following ITU-T Recommendations and other references contain provisions which, through reference in this text, constitute provisions of this Recommendation. At the time of publication, the editions indicated were valid. All Recommendations and other references are subject to revision; users of this Recommendation are therefore encouraged to investigate the possibility of applying the most recent edition of the Recommendations and other references listed below. A list of the currently valid ITU-T Recommendations is regularly published. The reference to a document within this Recommendation does not give it, as a standalone document, the status of a Recommendation.

[ITU-T F.749.13] Recommendation ITU-T F.749.13 (2021), *Framework and requirements for civilian unmanned aerial vehicle flight control using artificial intelligence.*

[ISO/IEC 13273-1] ISO/IEC 13273-1:2015, *Energy efficiency and renewable energy sources – Common international terminology – Part 1: Energy efficiency.*

3 Definitions

3.1 Terms defined elsewhere

This Recommendation uses the following terms defined elsewhere:

3.1.1 artificial intelligence (AI) [ITU-T F.749.13]: An interdisciplinary field, usually regarded as a branch of computer science, dealing with models and systems for the performance of functions generally associated with human intelligence, such as reasoning and learning.

3.1.2 big data [b-Viktor]: A term that describes the large volume of data – both structured and unstructured – that inundates a business on a day-to-day basis. Big data can be analysed for insights that lead to better decisions and strategic business moves.

3.1.3 energy consumption [ISO/IEC 13273-1]: Quantity of energy applied.

3.1.4 energy efficiency [ISO/IEC 13273-1]: The ratio or other quantitative relationship between an output of performance, service, goods or energy, and an input of energy.

3.1.5 energy saving [ISO/IEC 13273-1]: Reduction of energy consumption following implementation of an energy performance improvement action.

3.2 Terms defined in this Recommendation

None.

4 Abbreviations and acronyms

This Recommendation uses the following abbreviations and acronyms:

2G	2nd Generation of wireless networks
3G	3rd Generation of wireless networks
4G	4th Generation of wireless networks
5G	5th Generation of wireless networks
AAU	Active Antenna Unit
AI	Artificial Intelligence
ARIMA	Auto-Regressive Integrated Moving Average
BS	Base Station
CRS	Cell-specific Reference Signal
EIRP	Equivalent Isotropic Radiated Power
KPI	Key Performance Indicator
LSTM	Long Short-Term Memory
LTE	Long Term Evolution
MDT	Minimization of Drive Test
MIMO	Multiple Input Multiple Output
mMTC	massive Machine Type Communications
MNO	Mobile Network Operator
MR	Measurement Report
NR	New Radio
O&M	Operation and Management
OFDM	Orthogonal Frequency Division Multiplexing
PA	Power Amplifier
PRB	Physical Resource Block
PM	Performance Measurement
RAN	Radio Access Network
RF	Radio Frequency
RRC	Radio Resource Control
RRU	Remote Radio Unit
RSRP	Reference Signal Received Power
SA	StandAlone
SINR	Signal to Interference plus Noise Ratio
TA	Timing Advance
UE	User Equipment
uRLLC	ultra-Reliable Low Latency Communications

5 Conventions

None.

6 Overview of energy consumption of 5G

6.1 Where is energy consumed?

To determine the potential for energy saving and emission reduction in a mobile network, it is necessary to understand the power consumption distribution in the network. In 2015, mobile networks worldwide consumed 90 TWh of electricity, a figure that is expected to grow to ~130 TWh in 2030 [b-ITU-T L.1470]. The majority of this is consumed by the radio access network (RAN), i.e., the base station (BS) sites.

In the RAN, the power consumption of a BS site is divided into two parts: the power consumption of the main equipment (BS) and the power consumption of auxiliary equipment (such as air conditioners). For an outdoor site, the power consumption of the site is mainly from the main equipment, while for indoor sites the auxiliary equipment can make up a significant part.

Main equipment (BS) power consumption can be divided into the following two types: compute power consumption, which refers to the power consumed by the baseband processing, including the power consumption of digital part processing, management and control, communication with the core network and other BSs; and transmission power consumption, which refers to the power consumed by the power amplifier (PA) and radio frequency (RF) parts.

The greater the output power of the BS, the larger the share of the BS power consumption that is transmission power consumption, and the larger the share of the transmission power consumption that is PA power consumption [b-Auer]. However, 5G introduces massive MIMO where the number of RF channels is increased significantly, which means that a larger share of the transmission power consumption comes from the other RF parts, even though the PA still is dominating. With lower output powers, the relative share of the compute power consumption is increasing, and so is the non-PA part of the transmission power consumption [b-Debaillie].

6.2 Baseline and variable power consumption

Power consumption at the site, BS or equipment level can be classified into baseline power consumption and variable power consumption. Simply put, the power consumption that does not vary with the load is called baseline power consumption, and the power consumption that is positively related to the load is called variable power consumption. For example, the power consumption of the PA varies with the load. However, when the load is zero, the power consumption of the PA is not zero because the PA power consumption can be divided into baseline power consumption and variable power consumption.

In general, we can approximate the power consumption model with a simple first-order linear model [b-Holtkamp]:

$$P = a \times T + b$$

where P represents the total power consumption, a represents the power consumption variation, T represents the traffic load, $a \times T$ represents the variable power consumption, and b represents the baseline power consumption.

The higher the percentage of variable power consumption, the stronger the dynamic capability of the equipment. In addition to the baseline power consumption b, the slope a of the curve is also important. The slope determines the magnitude of the variable power consumption change with the load. Therefore, the primary function shown in Figure 1 is not an ideal scenario. The concave curve of the origin is passed. For example, a quadratic curve $P = a \times T^2$ has better dynamic capability than a primary curve.

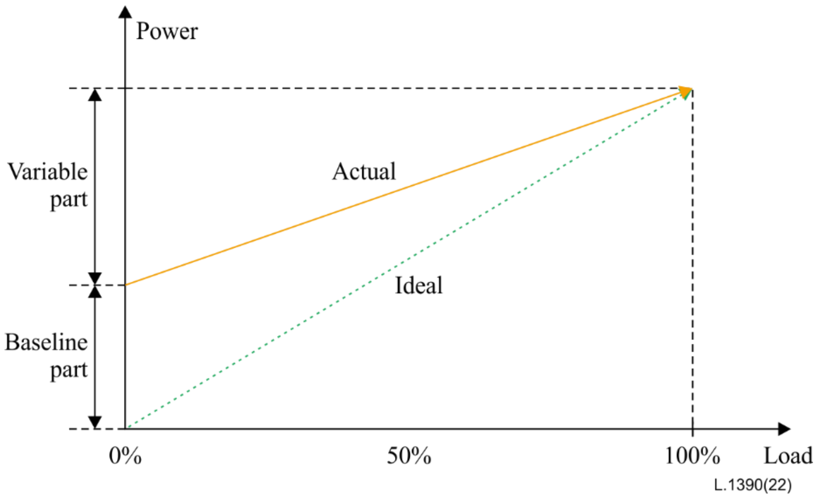


Figure 1 – Linear approximation model for power consumption

To improve the variable power consumption capability of an item of equipment, the hardware capability must be improved to reduce the proportion of baseline power consumption. On the other hand, when no data is transmitted, the energy saving shutdown capability of a component corresponding to the baseline power consumption is improved. Current mainstream RAN energy saving technologies (see clause 8) mainly reduce baseline power consumption *b*, and the improvement of slope *a* depends on the continuous evolution of the hardware. In a field network, the BS operates in light load and medium load most of the time. Therefore, the performance of this power consumption curve under low and medium loads has the greatest impact on the actual daily energy consumption of the network. In addition, low load and medium load are the main scenarios where the energy saving feature takes effect.

7 Energy saving design principles

From the energy consumption analysis in clause 6, it is possible to formulate some energy saving design principles.

7.1 Dynamic scaling

The dynamic capability is the capability of scaling power consumption with real-time changes of service loads. The dynamic capability is decomposed into the capability of scaling resource consumption with changes of service loads, and the ability of equipment power consumption to scale as resource consumption changes.

1) **Resource on-demand scaling**: Based on network KPIs and user QoS requirements, time-, space- and frequency-based resource occupation and air-interface power resource allocation are adjusted, implementing real-time dynamic scaling. Especially in low and medium load scenarios, reducing resource overhead through proper scheduling is a key path for energy saving.

   The evolution of wireless networks is a process of expanding network capacity and resources to cope with increasing service requirements. The resources are increased to meet the peak capacity of the network. However, traffic is tidal, and the proportion of peak scenarios in a day is not so high. It is therefore necessary to adjust the resources to the required demand.

2) **Power consumption scales with resources**: When resource consumption decreases, equipment power consumption should also decrease. The resource herein may be a bandwidth, a quantity of carriers, a quantity of channels, a transmit power or the like. For example, transmission power consumption varies with the number of RF channels and PA

output power, while compute power consumption typically varies with the bandwidth and the quantity of channels [b-Debaillie].

7.2 Shutdown capabilities

When scaling power consumption with resources, the static power consumption may become an obstacle. In other words, when scaling down resources the power consumption reaches a level (the static power consumption) where it does not scale any more. In such cases, a shutdown capability of the hardware component(s) is desirable, i.e., a deactivation of one or more components which decreases the static power consumption stepwise. A drawback with this is that the component is taken out of service, and reactivating it will cause a delay.

The energy saving gain from shutdown capabilities depends on three dimensions as illustrated in Figure 2. These are *S*, scenario (shutdown scenario), *T*, time (shutdown duration) and *D*, depth (shutdown depth). An improvement in shutdown scenario, shutdown duration and shutdown depth leads to an improvement in overall energy saving capability.

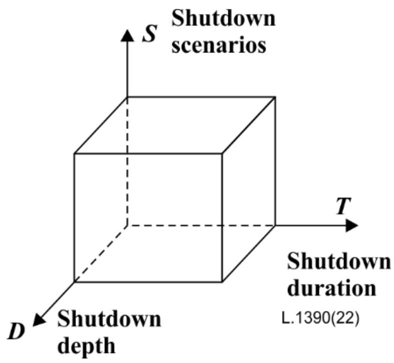


Figure 2 – Three dimensions of shutdown capabilities

An extended shutdown scenario can be that parameters are adjusted such that the shutdown can be applied more often. An improvement of the shutdown duration can be achieved by reducing the common information overhead in no load or light load scenarios, or performing aggregation scheduling for small-packet services. Finally, the shutdown depth is related to how many hardware components can be deactivated.

Furthermore, the three dimensions are not independent, but are mutually coupled and mutually constrained. When one dimension is strongly expanded, the other two dimensions may be affected. For example, increasing the shutdown depth increases the energy saving gain at the time when the shutdown takes effect, but increasing the shutdown depth may increase the wakeup duration [b-Debaillie]. The increase of the wakeup duration affects the application scenarios and the possibility of entering the sleep state. The overall gain of the whole day may not be the optimal state. Therefore, these three dimensions need to be considered comprehensively in the design of the solution and finding a good balance between them should be strived for.

7.3 Trade-offs

Energy saving involves various trade-offs, as discussed in clause 7.2. Another trade-off is between **network performance and energy saving**. Based on the impact on performance, many energy saving technologies are lossy as they scale resources, and the number of resources is closely related to performance. Therefore, it is difficult to achieve lossless performance. On the other hand, there is a large margin for network experience in off-peak hours, such as night. If the margin is properly squeezed out, energy saving can be harvested. However, how to squeeze this space will involve another issue, the qualitative and quantitative analysis of the impact of various energy saving measures on performance. In many scenarios, this impact cannot be accurately modelled in a white box manner. Although certain parameter thresholds are designed for most features to control the impact on performance, it is difficult to provide accurate guidance on how to adjust parameters. AI might be a tool to handle this, as will be discussed in clause 9.

Another trade-off is between **network energy saving and UE energy saving**. In most cases, network energy saving is decoupled from UE energy saving. However, trade-offs exist in some scenarios. For example, to save power for items of UE, the network performs substantial adaptation in the design of common signalling, and these adjustments usually increase the overheads on the network side. However, an Internet of Things terminal has a strict requirement on low power consumption, which exacerbates this contradiction. The terminal may selectively listen to a paging of a network for energy saving, but the network cannot arbitrarily reduce its paging density.

The number of items of UE in a cell fluctuates. However, the network needs to implement flexible scaling of common signalling overheads to reduce the power consumption of the BSs in light load scenarios. The UE side needs to be aware of and compatible with the dynamic adjustment of the common signalling on the BS side to reduce the impact on processes such as initial UE access and cell handover and reselection.

8 Energy saving technologies for 5G RAN

5G will add many new functionalities to the RAN and will also deploy more resources in the form of carriers, bandwidth, transmit antennas and output power. This not only means increased capacity and capabilities of the network, by following the design principles in clause 7 there are also large opportunities for energy saving technologies.

However, the complexity of the 5G network and the difficulty of operation and management will also increase. This also holds for the management and control of energy saving technologies, as other aspects such as coverage, interference, user QoS and so on also need to be considered when using the different energy saving technologies. It is difficult to use a fixed or simple algorithm to guarantee optimal performance. Therefore, AI needs to be introduced, and how to use AI technology to realize energy saving applied to the operation and management of wireless communication units becomes more and more important. Therefore, clause 9 will be dedicated to AI-based energy saving, while this clause will focus on the energy saving technologies themselves.

8.1 Time-domain energy saving

Time-domain energy saving utilizes symbols, timeslots or subframes where no valid information is transmitted for energy saving; this is carried out by shutdown of related components. Symbol power saving in LTE, sometimes referred to as cell discontinuous transmission (DTX) [b-Frenger], is a well-known example for this in which the PA is deactivated in symbols where no information is to be transmitted, as illustrated in Figure 3.

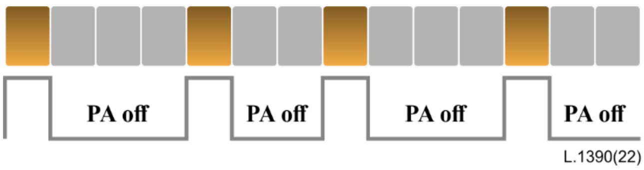


Figure 3 – Illustration of time-domain energy saving: During symbols with no information to transmit, the PA is deactivated

However, even an empty LTE carrier transmits the cell-specific reference signals (CRS) approximately every 0.2 ms, which means that only very short (2–3 OFDM symbols) component de-activations are possible. 5G has addressed this issue by drastically reducing the signal load in idle mode to allow for more time-domain energy saving. The most necessary control signals for access are still broadcast but many other signals are only transmitted on-demand from the accessing user devices. Furthermore, the periodicity of the necessary control signals can be configured between 5 ms and 160 ms. For a coverage-providing carrier the default periodicity is 20 ms [b-3GPP TS38.213]. This means that in idle mode a 5G carrier can have approximately 100 times longer silent periods than an LTE carrier (20 ms vs 0.2 ms) [b-Frenger], during which time-domain energy saving can be applied.

Furthermore, also when the carriers are loaded, time-domain energy saving can be applied. Due to the bursty nature of traffic, empty symbols are common also in loaded traffic scenarios. It is also possible to create empty symbols, time slots and even subframes by smart scheduling decisions. Hence, time-domain energy saving is a very important energy saving technology that should be used in 5G.

8.2 Spatial-domain energy saving

In spatial-domain energy saving, a number of the RF channels are deactivated in low load scenarios [b-Skillermark] [b-Halbauer]; see Figure 4. This is sometimes referred to antenna or MIMO muting or RF channel shutdown. The idea is that the remaining capacity should be enough to serve the traffic, but coverage and data rates may be affected since some of the PAs and thereby the available output power is taken out of service. However, there are methods to compensate for this, e.g., by common signal power boosting.

Since 5G in general, and massive MIMO in particular, uses more antennas and RF channels than previous generations, spatial-domain energy saving is an important energy saving technology that should be used in 5G.

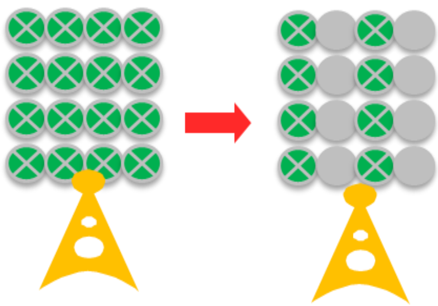


Figure 4 – Illustration of spatial-domain energy saving: During low load periods, a number of antenna elements and corresponding RF channels are deactivated

8.3 Frequency-domain energy saving

Frequency-domain energy saving relates to reducing the available frequency bandwidth and thereby saving energy. There are two classes of frequency-domain energy saving:

1) **Large-scale**: In this case an entire carrier is shutdown, and consequently it is sometimes referred to as carrier shutdown. Carriers corresponding to some frequency bands or frequencies are shut down, as illustrated in Figure 5. When these carriers are mapped to independent physical hardware components (e.g., a radio unit), corresponding components can be shut down and thereby save energy.

2) **Small-scale**: Such as bandwidth shrinking and subcarrier shutdown. In this case only carrier specifications are adjusted. The entire carrier is still working, and component shutdown cannot be implemented. In this case, the specifications of certain processing units can only be adjusted to reduce power consumption, which means that the dynamic capability (the *a* parameter) is crucial for the achievable energy saving.

Figure 5 – Illustration of large-scale frequency-domain energy saving, carrier shutdown: One of the two carriers is shutdown, and the related radio unit is deactivated to save energy

With the roll-out of 5G on new frequency bands, in particular large-scale frequency-domain energy saving, such as carrier shutdown, will be an important energy saving technology that should be used. With low load in the network and overlapping network coverage, some carriers can be shut down to save energy. This can also be coordinated over different radio access technologies. Taking the overlapping network of NR and LTE as an example, we can consider NR is the capacity system and LTE the basic coverage system. If the NR traffic is low, the NR can be intelligently shut down and the traffic transferred to LTE at the same time. Once LTE service exceeds a certain threshold, the NR carrier is reactivated. In this way, the power consumption of the whole network changes with the traffic volume.

8.4 Power-domain energy saving

Power-domain energy saving relates to reducing or scaling down the PA output power by different means, thereby reducing the transmission power consumption. Due to an increased number of carriers, wider bandwidths and a higher number of transmit antennas, the transmit power requirement of 5G equipment is typically higher compared with previous generations of communication technologies. Unfortunately, this contradicts energy saving objectives, as a higher transmit power requirement typically implies a higher PA output power and thereby power consumption. Hence, it is recommended to pursue different methods to reduce PA output power, while still maintaining all network performance KPIs.

One track that should be used is to improve the energy transmission efficiency. This can be done both with software and hardware. Beam optimization software can be used to optimize the link between the BS and the UE, thereby improving the beam pointing precision and reducing transmit energy waste, which also means that lower output power is required. Appendix I introduces this technology in more detail.

In the hardware domain, an obvious way to improve energy transmission efficiency is to utilize the antenna domain and design antennas with higher antenna gain. By doing that, the output power from the power amplifier to the antenna can be lower, while utilizing the higher antenna gain to generate the desired radiated power (EIRP) from the antenna. The benefit is maintained coverage with lower equipment power consumption. Appendix II and Appendix III introduce two example technologies for realizing this: ultra-large antenna arrays and Luneberg lens antennas, respectively.

9 AI-based energy saving for 5G RAN

The research and application progress of artificial intelligence (AI) in the field of cellular networks is rapidly moving forward. It is believed that AI can be introduced into the network on three levels: network element intelligence, operation and management (O&M) intelligence (see e.g., [b-ITU-T M.3080]), and service intelligence, with the principles of being tiered, on-demand and phased. In this way, ubiquitous intelligence can be achieved.

In this Recommendation, it is proposed to optimize and control the energy saving technologies introduced in clause 8 using AI technology. This results not only in a more efficient utilization of energy saving technologies and consequently more energy savings, but also a self-adaptive network reducing the human resources required for O&M.

9.1 AI technology

Artificial intelligence is the area of computer science focusing on creating machines that can engage in behaviours that humans consider intelligent. It combines computer science, physiology and philosophy and is a broad topic consisting of different fields, from machine vision to expert system.

The element that the fields of AI have in common is the creation of machines that can "think". The ability to create intelligent machines has intrigued humans since ancient times, and with the advent of the computer and over 50 years of research into AI programming techniques, the dream of smart machines is becoming a reality. For more details, see [b-ITU-T L.Sup43].

9.2 Energy saving based on AI

Many MNOs are running 2G, 3G, 4G and 5G networks at the same time. The spatial and temporal distribution of cellular network traffic varies significantly, with obvious peaks and troughs. At the same time, basic functions applied to the entire cellular network are not site specific, resulting in unnecessary inefficiencies due to ignoring the traffic and neighbouring site patterns that varies from site to site, especially in a more complex network.

By introducing AI and big data technology, a more precise energy saving strategy based on site specific traffic and other site-related conditions can be achieved. The AI-based RAN energy saving solution can forecast the traffic load of BSs based on historical traffic load, service type, site coverage and user behaviours. An energy saving strategy can automatically be configured based on co-coverage identification and configuration detection by AI. The suitable energy saving strategy combined with different energy saving functions (see clause 8), including an initial relative threshold to the scenario and executable energy saving time schedule, will be enabled for the sites that are expected to have energy saving effects. Meanwhile, the AI-based RAN energy saving solution can also ensure the balance between network power consumption and network performance based on sufficient model training.

The basic functions of an AI-based RAN energy saving solution should include but not be limited to the following:

1) **Scene identification**: Based on history traffic model analysis, the application scenario should be automatically identified, such as business district, residential areas, high-speed train, etc., and thus more suitable initial energy saving strategies will be selected.

2) **Traffic forecast**: In most cases, the forecast matches well with the actual traffic, which means that energy saving can be enabled on far more occasions. The modelling is based on historical traffic data (physical resource block (PRB) utilization, RRC connected users, online users, throughput, etc.), special days or holidays, user behaviour, etc. and then time series algorithms will be applied for traffic load forecast.

3) **Co-coverage identification**: To achieve an efficient energy saving strategy specific to a certain cell, the coverage of the cell and its neighbouring cells' coverage and traffic load all need to be taken into consideration. The reason is that any shutdown of a cell with direction of its users to neighbouring cell(s) has to rely on the good availability of the neighbouring cell(s) including coverage and capacity. Thus, co-coverage identification relying on operating parameters (site ID, longitude, latitude, antenna height and azimuth) and MR (measurement report) data (cell ID, RSRP (reference signal received power), SINR (signal to interference plus noise ratio), TA (timing advance)) is needed. Based on this information, the cell coverage performance can be calculated to identify the relationship between the co-coverage cells.

4) **Online iteration and parameter optimization**: In order to improve the energy saving efficiency, online iteration and optimization of parameters can be used instead of the traditional ways which do not take site variations into consideration. In this way, a more precise energy saving strategy tailored to each site is achieved.

9.3 Architecture of AI-based energy saving

Figure 6 shows the overall architecture of an AI-based energy saving solution. On top is the intelligent application platform, where the AI algorithms are executed based on data from the underlying network management layer. The output from the AI algorithms are fed back to the network management layer and used for configuration of the BSs in the network element layer. This is adopted to achieve the maximum balance between the system performance and the energy saving effect, so as to achieve the network energy saving and consumption reduction.

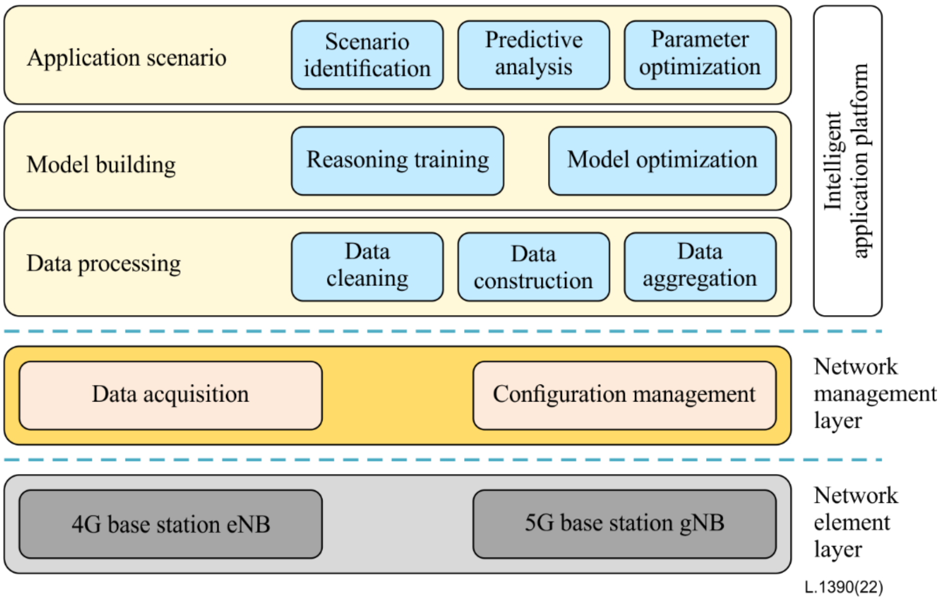


Figure 6 – Overall architecture of 5G intelligent energy saving solution

By shutting down the time-, spatial- and frequency-domain resources that are not utilized and keeping network capacity adequate yet to a minimum, network energy consumption can be optimized in line with the network traffic load forecast. The AI-based energy saving solutions can take into account the different efficiency levels of frequency bands and factors in that the power efficiency of different resources can vary. By directing users from their less-power-efficient spectrum band(s) to one or more other bands that are more power-efficient, more radio resources can be shut down more often to lower network energy consumption. An example practice, also including service awareness, is given in Appendix IV.

Appendix I

Example of 5G power-domain energy saving practices – Beam optimization energy saving

(This appendix does not form an integral part of this Recommendation.)

With the development and deployment of 5G technology, the network coverage scenarios are gradually diversified. At the same time, large-scale MIMO antennas introduce more dimensional adjustable parameters, including horizontal beamwidth, vertical beamwidth, azimuth angle, down tilt angle, number of beam scans, etc. Therefore, the traditional manual beam adjustment method is no longer feasible. In order to achieve automatic adjustment and improve radiation efficiency, the beam is adjusted adaptively and flexibly to achieve beamforming, so as to achieve the best coverage effect and performance gain in various scenarios and to realize the dynamic coordination of antenna coverage area following user position, and finally achieve the goal of optimizing beam direction, aligning hotspot area and reducing energy consumption.

Beam optimization is first used to distinguish cell coverage scenarios such as low-rise buildings, high-rise buildings, roads and squares through scene recognition technology. At the same time, the geographical area is divided into many location grids, and different scenes are calculated according to the threshold set by the algorithm. For example, the proportion of road scenes is equal to the total grid of road scenes/cell coverage. When the proportion of road scenes is higher than a certain threshold, this scene is considered to be a road scene. This is illustrated in Figure I.1 and Figure I.2.

Figure I.1 – The proportion of scene in the grid

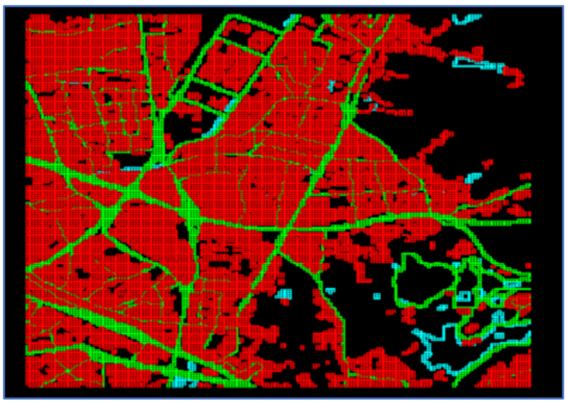


Figure I.2 – Road scene recognition and rendering

Based on historical MDT, PM data and big data machine learning algorithms, the time and space of user hotspot distribution is predicted, and after a high price reduction is performed on the parameter space of each cell to be optimized, the two indicators RSRP and SINR are evaluated to form a cost function and select the appropriate weight combination from the beam library according to the scene characteristics.

In addition, considering that the 5G Massive MIMO antenna has more streams, the beam downlink can optimize each sub-beam to achieve accurate coverage for each item of UE, so the energy is more focused, and the anti-interference ability is stronger. In addition, the beam uplink receives gain through multiple antennas, so the user experience is better. The shaping of the sub-beams can effectively improve the spectrum efficiency and avoid excessive waste of resources, finally, achieving energy saving effects by beam optimization. This is illustrated in Figure I.3 and Figure I.4.

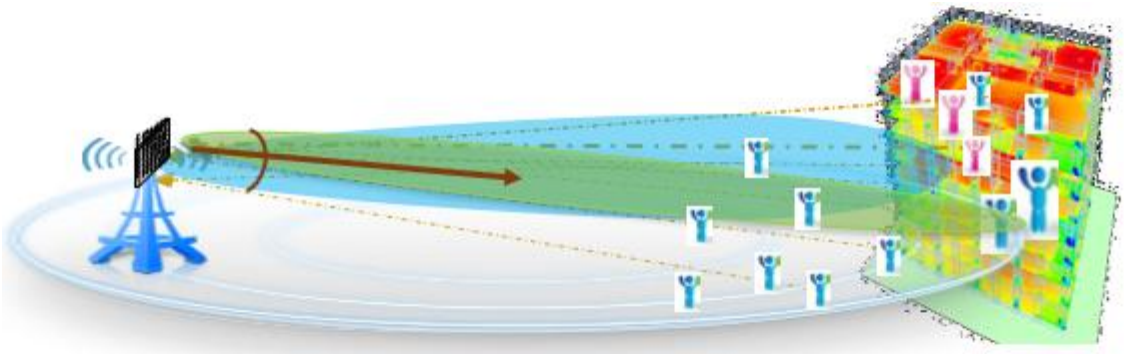


Figure I.3 – Beam optimization for every UE

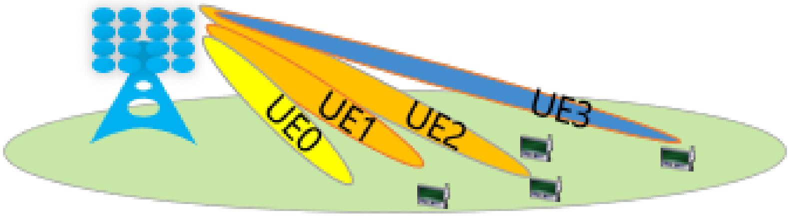


Figure I.4 – Sub-beam and UE distribution

Appendix II

Example of 5G power-domain energy saving practice – Ultra-large-scale antenna array with beam pattern optimization

(This appendix does not form an integral part of this Recommendation.)

For antenna array of AAU, the larger size of the antenna array, the narrower beam of the channel, thus, the more focused channel energy and the longer distance of the network coverage. With the introduction of an ultra-large-scale antenna array, the uplink and downlink coverage can be increased synchronously without increasing the transmission power. This can also be used for energy saving with maintained coverage; with the ultra-large-scale antenna array the output power from the power amplifier to the antenna can be lower, while utilizing the higher antenna gain to generate the desired radiated power from the antenna. This results in maintained coverage with lower equipment power consumption.

One method to generate higher antenna gain is to use an ultra-large antenna array. This not only improves the antenna gain, the larger array also forms narrower beams which spread less interference, and consequently the network performance is also improved.

A trial with such ultra-large-scale antenna arrays was deployed in Xiamen city, which doubled the size of the antenna array of the AAU (elements from 192 to 384, see Figure II.1) and used new materials and architectures in manufacture. It adopted adaptive beam optimization and intelligently adapts the user's wireless channel changes to improve the utilization efficiency of air-interface resources, and adopts high-resolution beam domain noise reduction to improve the efficiency of multiuser pairing. This enables the new AAU to achieve "accurate-alignment", to be "fast-following" and offer "good-pairing", which can greatly improve user experience and cell capacity.

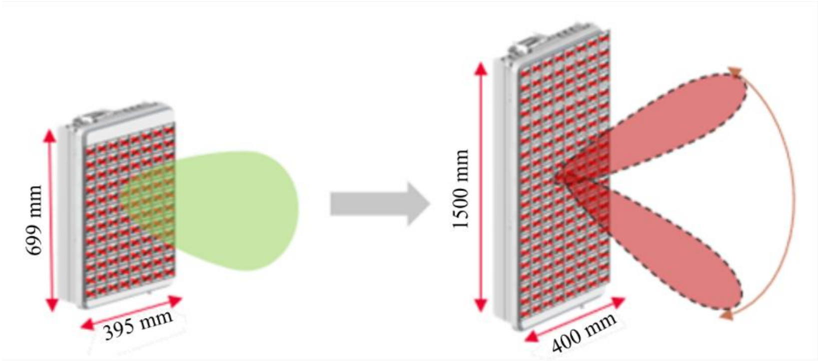


Figure II.1 – Comparison of traditional AAU and new Architecture AAU (number of antenna elements is from 192 to 384)

Test results show that compared with the traditional solution, the new AAU can increase the cell's uplink coverage and downlink coverage, and the average experience of edge users can be increased by 20%. If the coverage index of the cell edge remains unchanged, the BS can be configured with lower transmission power, thereby reducing the energy consumption of the BS. Compared with traditional AAU, the energy consumption can be reduced by about 30%.

Therefore, the use of ultra-large-scale antenna arrays shows great potential to improve coverage and reduce energy consumption. Through the integration and innovation of new architectures and new algorithms, both network performance and energy saving can be achieved, helping MNOs to build better and greener 5G networks.

Appendix III

Example of a 5G power-domain energy saving practice – High gain antenna-lens antenna

(This appendix does not form an integral part of this Recommendation.)

With the continuous development of mobile communication networks, 4G/5G networks have basically achieved full network coverage; however, there are also many coverage problems that are difficult to solve, such as coverage of long and narrow scenes, 5G high-frequency bands and large penetration attenuation.

As a new type of antenna using the principle of the Luneburg lens (Figure III.1), the function of the relationship between the refractive index *n* and the radius of the lens antenna is:

$$n = (2 - r/R)/2$$

where r is the radial distance from the centre of the sphere and R is the radius of the sphere. When $r = R$, $n = 1$, and at the centre of the sphere ($r = 0$), $n = 2$.

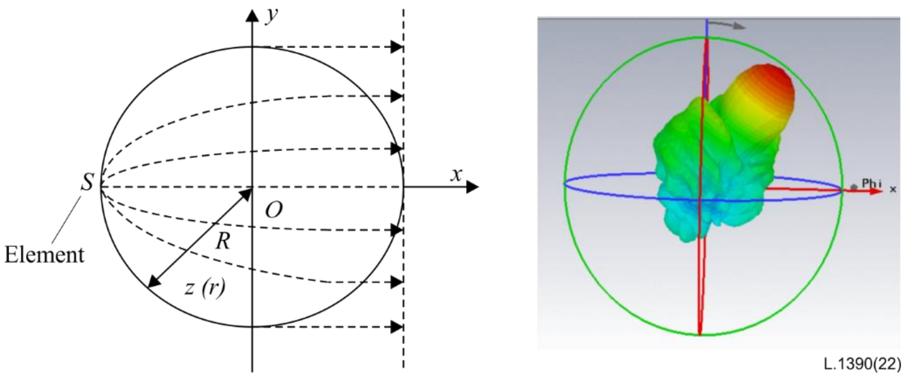


Figure III.1 – Principle of the Luneberg lens

As a new type of antenna, the lens antenna has good beam convergence, can converge incident electromagnetic waves of a specific wavelength to a certain point on the spherical surface and can convert spherical or cylindrical waves into plane waves. Therefore, the lens antenna can effectively improve radiation efficiency and reduce energy consumption.

The lens antenna has two main advantages as follows:

1) Compared with the traditional plate antenna (Figure III.2), the lens antenna has a higher antenna conversion efficiency. Because the beam gain of the traditional plate antenna is formed by stacking elements, the internal feeding loss of the antenna is larger, and the input signal is attenuated more. The conversion efficiency of the traditional plate antenna is between 50% and 75%, while the feed line of the lens antenna is relatively simple, the signal attenuation is almost 0 and the conversion efficiency is above 90% on average. Therefore, the conversion efficiency of the lens antenna is much higher than that of the traditional antenna.

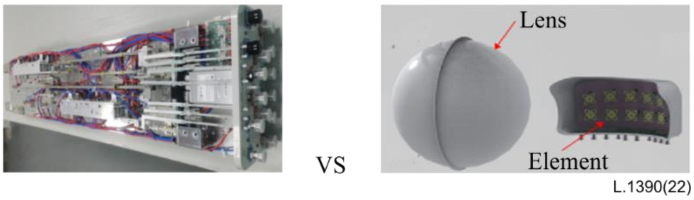


Figure III.2 – Traditional plate antenna vs Luneberg lens antenna

The experiments of the 5G network show that the remote radio units (RRUs) with the same output power are used to feed the traditional plate antenna and the lens antenna. The RSRP (field strength) of the lens antenna with a gain of 16.5dBi is higher than that of the plate antenna with a gain of 20dBi; under the same fringe field strength requirements, the usage of lens antennas can effectively reduce the power of BS equipment by more than 80%.

2) Since the vertical beamwidth of the lens antenna is wider than that of ordinary antennas, it is more advantageous in the coverage of striped scenes. Therefore, the vertical half-power beamwidth of the lens antenna is between 12–30 degrees, so the lens antenna has a better coverage depth *D*:

$$D = H/\tan(\alpha - \theta/2)$$

where α is the down tilt angle, H is the antenna height, and $\theta/2$ is the vertical half-power angle.

It can be seen from the above formula that under the conditions of fixed height and input power, the greater the value of θ, the longer the coverage distance, which can effectively reduce the radiation power and reduce the energy consumption of the equipment (see also Figure III.3).

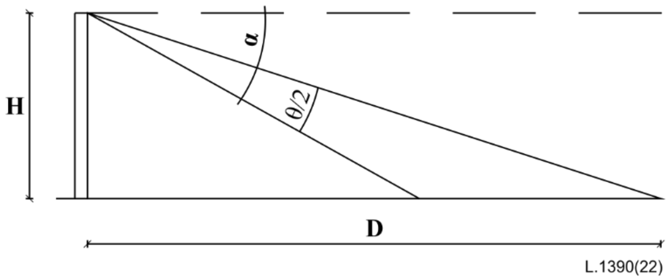


Figure III.3 – Illustration of antenna coverage

Based on the above characteristics, the lens antenna has a good coverage characteristic in high-speed railway scenes. Due to problems such as large insertion loss and Doppler effect in high-speed railway, the distance between stations on the existing network has been becoming closer and closer in recent years. For operators, the energy consumption of the equipment on the BS is becoming higher and higher, and the investment cost is also increasing.

In an actual case, a high-speed railway section with a total mileage of about 32 km is covered by a high-speed railway dedicated network. The average distance between the BSs is more than 1.3 kilometres, and the number of BSs is 25. The coverage effect is relatively poor when using traditional plate antennas (Figure III.4). After testing, the average field strength (RSRP) is only below −100 dBm, and the average SINR is only 6.56. The user experience is poor in practice.

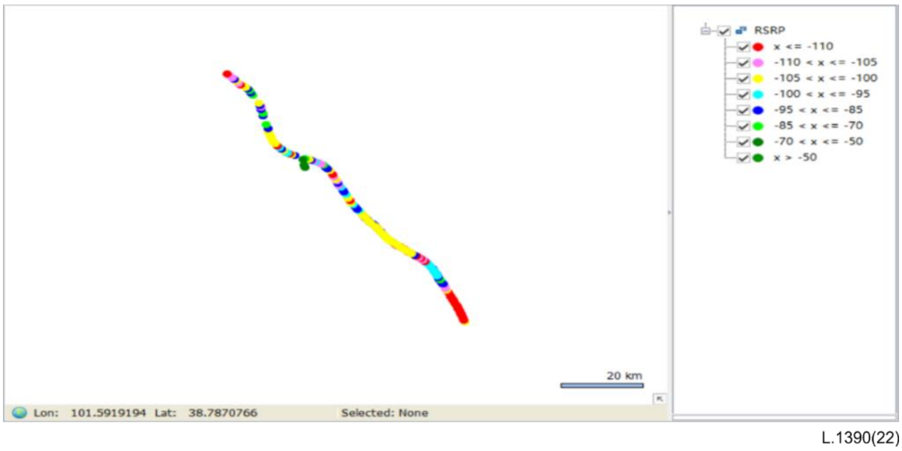


Figure III.4 – Trial results for traditional plate antenna

In order to improve the coverage level, local operators need to double the number of sites to 50 by using traditional antennas.

Using lens antennas to replace the original traditional plate antennas, the coverage has been greatly improved while keeping the site and transmitting power unchanged (Figure III.5). Test shows that the coverage distance of the lens antenna is 30-50% higher than that of the traditional antenna, and the coverage distance of the single antenna is increased by more than 300 metres. The reception level of edge users can be increased by 5 to 6 dBm, and the distance between the BSs and the edge coverage indicators remain unchanged. Under these circumstances, the BS can be configured with a lower transmission power, thereby reducing the energy consumption of the BS, which is more than half of the energy consumption compared with traditional antennas.

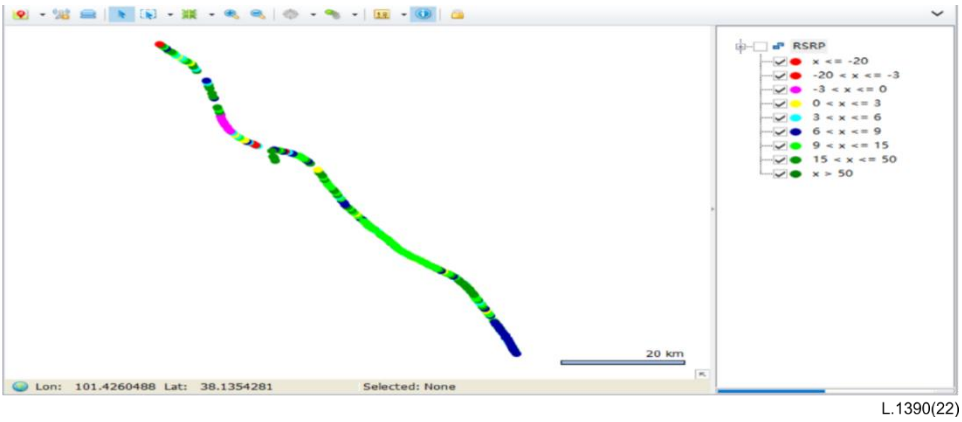


Figure III.5 – Trial results for lens antenna

According to Table III.1, the coverage effect of the lens antenna on the high-speed rail has been greatly improved while a large amount of construction resources has been saved.

In summary, as a new type of antenna that has emerged in recent years, the lens antenna has brought a new direction to the development of mobile communication networks. It can effectively improve the coverage efficiency and reduce the power consumption with its excellent radiation characteristics and good beam characteristics.

Table III.1 – Summary of trial results

Comparison test	Average RSRP	Average SINR	LTE coverage ratio (RSRP > −110 and SINR > −3)
Traditional antenna	−101.63 dBm	6.56	79.19%
Lens antenna	−94.33 dBm	11.75	99.25%

Appendix IV

Example of energy saving practice based on AI – Service awareness energy saving for 4G/5G coordination

(This appendix does not form an integral part of this Recommendation.)

AI-driven-energy-saving solutions with traffic forecast improve the energy saving efficiency of basic functions. H in most multimode and multifrequency cellular networks, it still has some limitation that service efficiency varies from mode to mode, and/or band to band. And if all services/users are concentrated in part of the network/band, more energy consumption could be saved after idle network/band shut down or deep sleep.

AI-driven service awareness in the 5G network should also be taken into consideration, which exploits the differences in energy efficiency of different types of services to deliver certain services to the most energy-efficient network, helping achieve the most efficient energy usage without impact on user experience [b-GSMA-2].

The solution involves providing automation capabilities for the service management layer and resource management layer. Based on network-level AI-based intelligent energy saving policy management and site energy saving scheduling control, the mobile network energy saving solution implements network scene adaptation, one site one policy and multinetwork collaboration for intelligent BS energy saving management (Figure IV.1). This maximizes network energy saving benefits while ensuring stable network performance and achieves the optimal balance between energy consumption and KPIs.

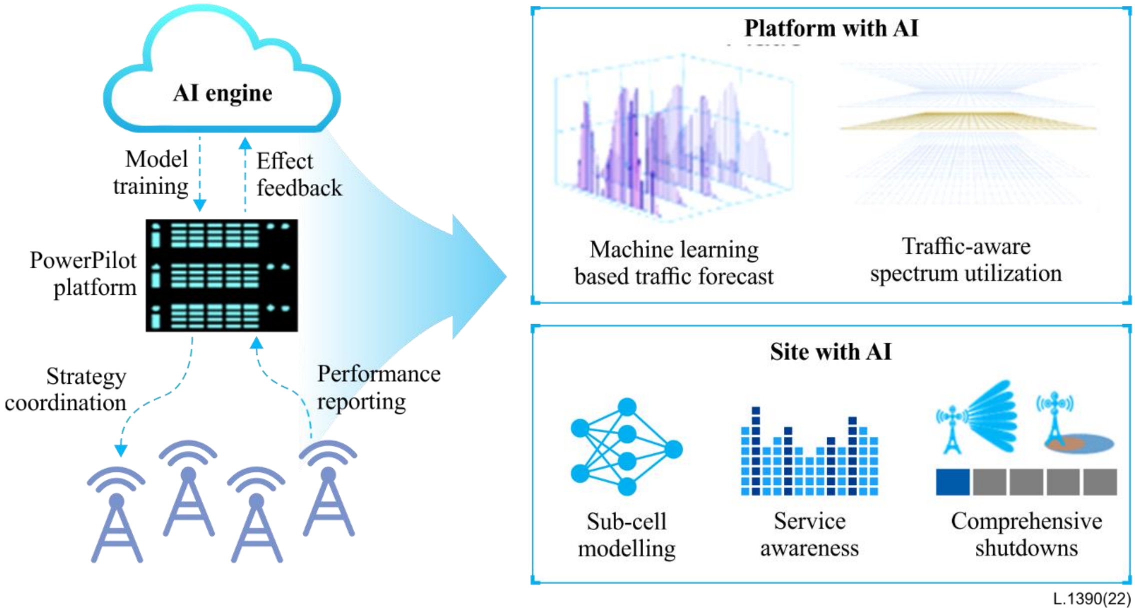


Figure IV.1 – Powered by AI, network energy saving accurate deployment

Cell-specific initial strategy

The initial energy saving strategy can automatically be configured based on co-coverage identification and configuration identification by AI technology. The suitable energy saving strategy combined with different energy saving technologies, including an initial parameter setting to the scenario and executable energy saving time schedule, will be enabled for the sites that are expected to have energy saving effects.

- Idle or low traffic period based on historical traffic analysis;

- Energy saving threshold based on network traffic load;
- Energy saving activation time based on threshold;
- Energy saving function combination.

Traffic load forecast

The intra-week sub-sequence split prediction method – in which each of the seven days in a week is put into the series of its corresponding days in all the weeks under consideration – is combined with cell types, holiday factors and forecast of network traffic load. After putting all the algorithm candidates (linear regressive, ARIMA (auto-regressive integrated moving average model) and LSTM (long short-term memory), second-order exponential smoothing, etc.) into tests, the one with the best results is selected.

The results of commercial application cases showed that the prediction accuracy exceeds up to 90% for uplink/downlink PRB utilization and RRC connected users.

Service awareness

Based on energy saving functions and AI-based traffic load prediction, a pilot practice solution to introduce AI-powered service awareness energy saving is presented here (Figure IV.2). By identifying service types and their energy efficiency differences, service requirements can be evaluated in real time and support the service with networks of higher energy efficiency to maximize energy efficiency in the entire network. To improve the network energy efficiency based on user redistribution, there are three main steps: target network/band selection, suitable user selection and consequent user direction. Service efficiency varies from network to network and/or band to band; the most energy-efficient network/band will be selected as a target and the most suitable users will be selected. Also, the energy efficiency pattern may change after user direction, leading a new round of optimization. Thus the three steps together form a closed loop.

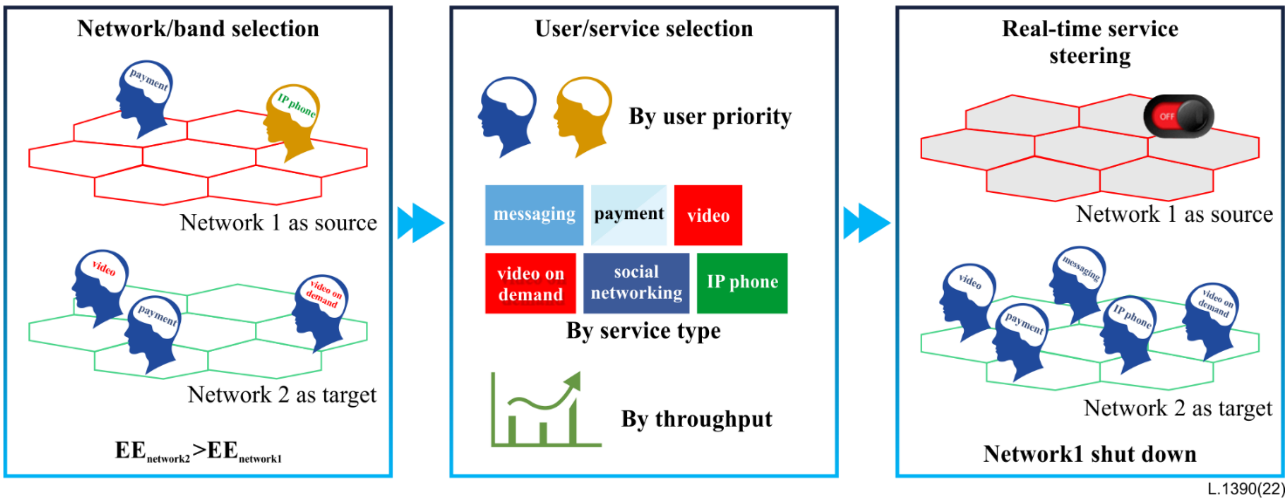


Figure IV.2 – Service awareness energy saving

Online iteration and optimization of the threshold

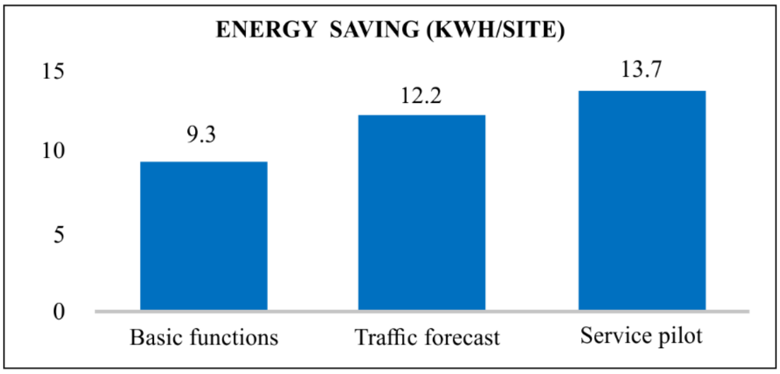
In order to improve the energy saving efficiency, online iteration and parameter optimization can be used instead of the traditional ways; it does not take site variations into consideration and results in safe but inefficiency energy saving settings.

A clustering algorithm is used to find the optimal energy saving parameter settings with the best efficiency and shortest time. In any case, when the KPI baseline is compromised, the parameter settings can be rolled back.

Application and performance

The solution was trialled in a commercial network in Chengdu city. The results with the Chengdu network show that over 35% of the network energy consumption of 4G/5G can be reduced without impact on the network performance or user experience.

This commercial trial in Chengdu 4G/5G network involves three phases. With only the basic energy saving function, about 9.3 kWh energy is saved daily per site; when the AI-driven traffic forecast is enabled simultaneously, approximately 12.2 kWh energy is saved daily per site. After the AI-driven service pilot is enabled, up to 13.7 kWh energy can be saved daily per site (Figure IV.3). During the trial, there was less impact to network performance, both in the 4G network and in the 5G network (Figure IV.4).



L.1390(22)

Figure IV.3 – Energy saving per site daily (kWh)

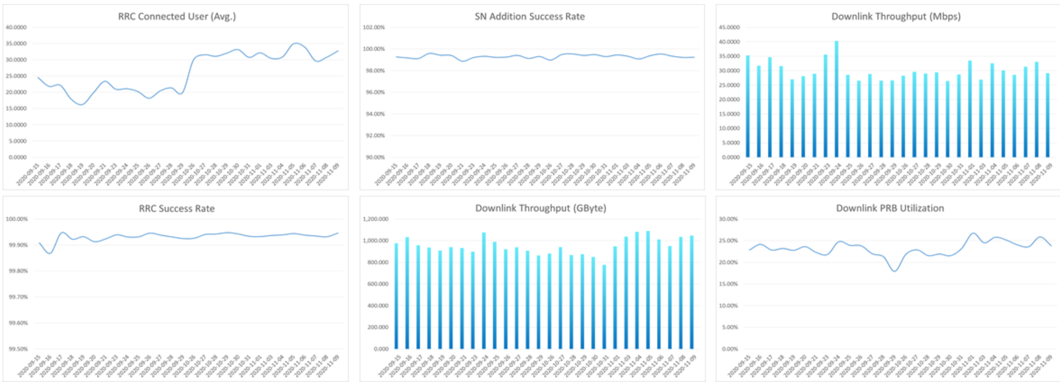


Figure IV.4 – Network performance

It is estimated that more than 5 million kilowatt-hours will be saved annually per thousand BSs and at least 2500 tonnes of carbon emissions will be reduced if this solution is deployed in the whole 4G/5G network in Chengdu.

According to typical network configuration calculations, the energy saved by the solution is twice as much as that of the conventional AI-based energy saving solutions, and it can save up to 20% of energy in a multimode network, thereby effectively reducing the operational expenditure.

Bibliography

[b-ITU-T L.1470] Recommendation ITU-T L.1470 (2020), *Greenhouse gas emissions trajectories for the information and communication technology sector compatible with the UNFCCC Paris Agreement*.

[b-ITU-T L.Sup43] Supplement ITU-T L.Sup43 (2021), *Smart energy saving of 5G base stations: Traffic forecasting and strategy optimization of 5G wireless network energy consumption based on artificial intelligence and other emerging technologies.*

[b-ITU-T M.3080] Recommendation ITU-T M.3080 (2021), *Framework of artificial intelligence enhanced telecom operation and management (AITOM).*

[b-3GPP TS38.213] 3GPP TSG RAN TS 38.213 (2019), *NR; Physical layer procedures for control (Release 16)*, v16.0.0. https://portal.3gpp.org/desktopmodules/Specifications/SpecificationDetails.aspx?specificationId=3215

[b-Auer] Auer, G., Giannini V., Desset, C., Godor, I., Skillermark, P., Olsson, M., Imran, M.A., Sabella, D., Gonzalez, M.J., Blume, O., and Fehske, A., (2011), *How Much Energy is Needed to Run a Wireless Network?* IEEE Wireless Communications, Vol. 18, No. 5, pp. 40–49 https://ieeexplore.ieee.org/document/6056691

[b-Debaillie] Debaillie, B., Desset, C., Louagie, F., (2015), *A Flexible and Future-Proof Power Model for Cellular Base Stations*, IEEE 81st Vehicular Technology Conference (VTC Spring), 2015. https://ieeexplore.ieee.org/document/7145603

[b-Frenger] Frenger, P., Moberg, P., Malmodin, J., Jading, Y., and Godor, I., (2011), *Reducing Energy Consumption in LTE with Cell DTX*, IEEE 73rd Vehicular Technology Conference (VTC Spring), 2011. https://ieeexplore.ieee.org/document/5956235

[b-Frenger] Frenger, P., and Tano, R., (2019), *More Capacity and Less Power: How 5G NR can Reduce Network Energy Consumption*, IEEE 89th Vehicular Technology Conference (VTC Spring), 2019. https://ieeexplore.ieee.org/document/8746600

[b-GeSI] Global e-Sustainability Initiative (2015), *#Smarter 2030: ICT Solutions for the 21st Century Challenges*. https://smarter2030.gesi.org/downloads/Full_report.pdf

[b-GSMA-1] GSMA (2019), *The enablement effect: The impact of mobile communications technologies on carbon emission reductions.* https://www.gsma.com/betterfuture/enablement-effect

[b-GSMA-2] GSMA (2020), *5G energy efficiencies: green is the new black*, https://data.gsmaintelligence.com/research/research/research-2020/5g-energy-efficiencies-green-is-the-new-black

[b-Halbauer] Halbauer, H., Weber, A., Wiegner, D., and Wild, T., (2018), *Energy efficient massive MIMO array configurations*, 2018 IEEE Globecom Workshops. https://ieeexplore.ieee.org/document/8644331

[b-Holtkamp] Holtkamp, H., Auer, G., Giannini V., and Hass, H., (2013), *A parameterized base station power model*, IEEE Communications Letters, Vol. 17, No. 11. https://ieeexplore.ieee.org/document/6600717

[b-Skillermark] Skillermark, P., and Frenger, P., (2012), *Enhancing energy efficiency in LTE with antenna muting, IEEE 75th Vehicular Technology Conference (VTC Spring)*. https://ieeexplore.ieee.org/document/6240248 [b-Viktor] Mayer-Schönberger, V. and Cukier, K. (2013), *Big data: a revolution that will transform how we live, work and think, Houghton Mifflin Harcourt, New York*.

SERIES OF ITU-T RECOMMENDATIONS

Series A	Organization of the work of ITU-T
Series D	Tariff and accounting principles and international telecommunication/ICT economic and policy issues
Series E	Overall network operation, telephone service, service operation and human factors
Series F	Non-telephone telecommunication services
Series G	Transmission systems and media, digital systems and networks
Series H	Audiovisual and multimedia systems
Series I	Integrated services digital network
Series J	Cable networks and transmission of television, sound programme and other multimedia signals
Series K	Protection against interference
Series L	**Environment and ICTs, climate change, e-waste, energy efficiency; construction, installation and protection of cables and other elements of outside plant**
Series M	Telecommunication management, including TMN and network maintenance
Series N	Maintenance: international sound programme and television transmission circuits
Series O	Specifications of measuring equipment
Series P	Telephone transmission quality, telephone installations, local line networks
Series Q	Switching and signalling, and associated measurements and tests
Series R	Telegraph transmission
Series S	Telegraph services terminal equipment
Series T	Terminals for telematic services
Series U	Telegraph switching
Series V	Data communication over the telephone network
Series X	Data networks, open system communications and security
Series Y	Global information infrastructure, Internet protocol aspects, next-generation networks, Internet of Things and smart cities
Series Z	Languages and general software aspects for telecommunication systems

Printed in Switzerland
Geneva, 2022