International Telecommunication Union

ITU-T

TELECOMMUNICATION
STANDARDIZATION SECTOR
OF ITU

Series L
Supplement 43
(05/2021)

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

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

ITU-T L-series Recommendations – Supplement 43

ITU-T

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
LOW COST SUSTAINABLE INFRASTRUCTURE	L.1700–L.1799

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

Supplement 43 to ITU-T L-series Recommendations

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

Summary

Supplement 43 to ITU-T L-series Recommendations explores how network energy-saving technologies that have emerged since the fourth generation (4G) era, e.g. carrier shutdown, channel shutdown and symbol shutdown, can be leveraged to mitigate fifth generation (5G) energy consumption. The document also analyses how enhanced technologies, e.g., deep sleep and symbol aggregation shutdown, have been developing in the 5G era. Supplement 43 to ITU-T L-series Recommendations details these fundamentals.

However, Supplement 43 to ITU-T L-series Recommendations is far from being sufficient; a revolutionized energy-saving solution should be considered. In response to the requirement for an intelligent and self-adaptive energy-saving solution, artificial intelligence (AI) and big data technology are introduced to form a more precise energy-saving strategy based on specific site traffic and other site-related conditions, thus improving the efficiency and reducing the personnel required. More details of an AI-driven smart energy-saving solution are elaborated.

Supplement 43 to ITU-T L-series Recommendations could help to achieve the most energy-efficient network with good performance and lower operating expense for mobile network operators (MNOs).

History

Edition	Recommendation	Approval	Study Group	Unique ID*
1.0	ITU-T L Supp. 43	2021-05-20	5	11.1002/1000/14762

Keywords

5G, artificial intelligence, base station, big data, energy efficiency, smart energy.

* 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

This is an informative ITU-T publication. Mandatory provisions, such as those found in ITU-T Recommendations, are outside the scope of this publication. This publication should only be referenced bibliographically in ITU-T Recommendations.

INTELLECTUAL PROPERTY RIGHTS

ITU draws attention to the possibility that the practice or implementation of this publication 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 publication 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

Supplement 43 to ITU-T L-series Recommendations

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

1 Scope

This Supplement examines energy-saving technology for fifth generation (5G) base stations (BSs). Some energy-saving technologies developed since the fourth generation (4G) era are explained in detail, while artificial intelligence (AI) and big data technology are introduced in response to the requirement for an intelligent and self-adaptive energy-saving solution. This Supplement also elaborates intelligent technical guidance for smart energy saving of 5G BSs.

2 References

None.

3 Definitions

3.1 Terms defined elsewhere

This Supplement uses the following term defined elsewhere:

3.1.1 energy efficiency [b-ITU-T L.1361]: Relation between the useful output and energy consumption.

3.2 Terms defined in this Supplement

This Supplement defines the following terms:

3.2.1 artificial intelligence (AI): The area of computer science that focuses on creating machines that can engage in behaviours that humans consider intelligent. It combines computer science, physiology and philosophy, i.e., it is a broad topic consisting of different fields, from machine vision to expert systems.

NOTE – Based on [b-de Garis].

3.2.2 big data: 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.

NOTE – Based on [b-Mayer-Schönberger].

4 Abbreviations and acronyms

This Supplement uses the following abbreviations and acronyms:

2G	second Generation
3G	third Generation
4G	fourth Generation
5G	fifth Generation
AAU	Active Antenna Unit
AI	Artificial Intelligence

ARIMA	Auto-Regressive Integrated Moving Average
BS	Base Station
CDT	Call Detail Trace
ID	Identifier
LTE	Long-Term Evolution
MIMO	Multiple Input Multiple Output
ML	Machine Learning
MNO	Mobile Network Operator
MR	Measurement Report
NR	New Radio
NSA	Non-Stand Alone
O&M	Operation and Maintenance
PA	Power Amplifier
PRB	Physical Resource Block
RAT	Radio Access Technology
RRC	Radio Resource Control
SA	Stand Alone
SVM	Support vector machine
TR	Transceiver

5 Conventions

None.

6 Specific contents

5G is the most advanced cellular technology in commercial deployment of our era. While 5G offers much faster speed, massive connections and much lower latency, and would enable a much bigger variety of new applications for both people's lives and vertical industries, it does increase the energy consumption of cellular networks.

While the overall energy efficiency of 5G is eventually expected to be better than any previous generation, energy consumption might initially be higher, when the terminal penetration rate is not very high or new killer services still need time to materialize. The initial energy efficiency of 5G can then be an issue in lowering network operation cost. [b-GSMA 2019a] suggests that a 5G network requires up to 140% more energy consumption than 4G. Energy-saving measures for mobile network operators (MNOs) are needs rather than options.

What is more important is that sustainability has risen to the top of the agenda for many industries, including telecommunications. MNOs need to rethink their usage of energy and impact on the environment, and this will have a profound effect on the way they plan and deploy next-generation networks. Thus, a collaborative energy-saving solution among equipment, sites and networks will become an inevitable trend in the 5G era.

7 Energy-saving technologies for a base station

There are two main methods of BS energy saving, including hardware and software.

Hardware energy saving is mainly achieved by BS equipment architecture design optimization, the increase of chip integration (e.g., baseband processing, digital intermediate frequency and transceivers (TRs)) and improvements in manufacturing technique. A 10 nm or 7 nm high-integration chip has been applied to improve computing capacity and reduce power consumption, and new materials, such as gallium nitride, are applied to improve the power amplifier (PA) efficiency of active antenna unit (AAU) equipment.

For software energy saving, it is very important to find the most efficient match of traffic load and network capacity in a flexible and dynamic way. Based on the different characteristics of services and network traffic load distribution in both the time and space domains, the software energy-saving solution should adopt a dynamic scheduling strategy to shut down PAs, TRs and other network elements without impact on user experience to reduce the redundant power consumption and maximize BS resource utilization efficiency.

Hardware energy saving is affected by semiconductor and fundamental other technologies, their massive-scale commercialization, and product design and development. In this Supplement, software energy saving is the focus.

7.1 Basic software energy-saving technologies for a base station

In commercial networks, traffic pattern may vary from site to site or hour to hour. Turning off all or parts of the equipment, or even putting it into sleep mode, when there is little or no traffic can save energy.

By shutting down PAs, TRs and other network elements that are not utilized while maintaining adequate yet minimum network capacity, energy consumption can be optimized in line with traffic load.

7.1.1 The fundamentals of a 4G base station

The beginning of network energy saving came with the fact that many sites had traffic peaks and troughs, which means certain parts of BSs could be shut down to save energy, and these included carrier frequency block, carrier frequency shutdown, channel shutdown and symbol shutdown.

7.1.1.1 Carrier frequency block

In a commercial cellular network, there are often multi-frequency and multi-mode networks. During periods of no or extremely low traffic, the carrier frequency block is the first technology deployed for energy saving. Blocking the carrier frequency manually through the maintenance operation command in operator-defined time can save energy.

Because the carrier is blocked manually without traffic load monitoring, it will cause online user call drop. Additionally, the carrier block is a time-scheduled function that is not activated to balance traffic load congestion. Although this function is very easy to realize, the user experience and network performance is seriously affected.

7.1.1.2 Carrier frequency shutdown

In order to solve the impact on user experience and network performance by carrier block, carrier frequency shutdown has been developed. In a commercial cellular network, low frequency or legacy network mode is the basic coverage and capacity layer, while high frequency or advanced network mode is the extra capacity layer. During periods of no or extremely low traffic, the extra capacity layer can be shut down by the BS system after users are handed over or redirected to the basic coverage layer. When traffic load exceeds the capacity of the basic coverage layer, the extra capacity carrier should be activated automatically by the BS system.

The carrier frequency shutdown function is suitable for multi-frequency networks with regular traffic distribution.

7.1.1.3 Channel shutdown

Since the 4G era, multiple input multiple output (MIMO) has been introduced, so that cells can transfer the signal through multiple channels. When network traffic load is low, parts of channels (PAs and TRs) can be shut down for energy saving. After these parts are shut down, the power spectrum density of the remaining channels should be increased in order to ensure that the entire cell coverage is unaffected. The physical resource block (PRB) usage rate, radio resource control (RRC) connected users and voice users are taken into consideration for cell traffic load assessment.

The channel shut down function is suitable for the single-frequency networks with regular traffic distribution.

7.1.1.4 Symbol or slot shutdown

Symbol shutdown has been deployed or activated in the network during medium traffic periods in which carrier shutdown and channel shutdown are unavailable.

Symbols in sub-slots are not always in effective use in a long-term evolution (LTE) system. The scheduler allocates a certain number of symbols for downlink data in accordance with the system load and service data forecasts, and turns off the PA to save energy when there is no information being transmitted. In particular, symbols without a cell reference signal, synchronized signal or broadcast messages can be shut down.

The scheduler can even concentrate user data in just a few sub-slots, so that more sub-slots without user data can be shut down, reducing energy consumption more often.

7.1.2 The fundamentals of a 5G base station

New technologies provide faster and more services that make 5G system more complex than 4G. However, 5G and 4G have in common the provision of services over a cellular network, signal transference over multiple channels, etc. Thus, 5G energy saving does not have to start from scratch, all appropriate 4G technologies can be leveraged.

However, 4G technologies alone are far from being sufficient, thus more new and enhanced technologies need to happen in 5G era such as equipment deep sleep, /new radio (LTE/NR) carrier cooperative shutdown, enhanced channel shutdown and symbol aggregation shutdown. The 5G NR standard allows more components to switch off or go to sleep when the BS is in idle mode and requires far fewer always-on signalling transmissions.

7.1.2.1 Equipment deep sleep

Equipment deep sleep, a basic function that has been introduced in the initial stage of 5G deployment, can be applied to maximize energy-saving efficiency. During periods of no or extremely low traffic, a radio frequency unit can be put into deep sleep with only an enhanced common public radio interface processing unit and power supply unit remaining active. Other units, e.g., TR, baseband and digital intermediate frequency, can be completely shut down for further energy saving. In order to have minimal impact on user experience, connected users are migrated before the deep sleep.

7.1.2.2 LTE/NR carrier cooperative shutdown

In a non-stand alone (NSA) or NSA/stand alone (SA) hybrid network scenario, if LTE and NR have co-coverage, the LTE/NR cooperative carrier shutdown function is introduced to shut down the NR carrier during 5G low traffic load period and hand over or redirect users to a 4G network through an X2 interface. The 5G carrier will be activated when a 4G network monitors an increase in NSA RRC users.

7.1.2.3 Enhanced channel shutdown

Massive MIMO has been introduced in the 5G network, which means more TR channels are required. For 5G 64TR AAU, enhanced channel shutdown supports smaller-grained channel shutdown. It can support 16, 32 and 48 channel shutdown settings. It is more flexible to deal with different traffic loads.

After the channel is shut down, there will be degradation to the total transmit power and antenna gain that the power spectrum density of the remaining channel should be increased to ensure that the entire cell coverage is not affected.

7.1.2.4 Symbol aggregation shutdown

The symbol shutdown reduces the total power consumption of PA module by discontinuous transmission when the network is under low load. When the BS traffic increases, the PA module immediately enters the working state. To improve power-saving efficiency, symbol aggregation shutdown is introduced.

When the traffic load is low, the BS can turn off some slots to save energy. In order to increase the proportion of idle slots, scheduling is carried out by centralizing data into certain slots. For example, priority is given to aggregating data into broadcasting, public channels and centralized transmission of reference signals in the slots. When the traffic load is increased, the normal slot scheduling is restored.

7.2 Recommended strategy for 4G/5G fundamentals

The time distribution of cellular network traffic often has obvious peaks and troughs, while the network configuration remains the same over a long period. One key to energy saving is to reduce inefficient consumption in low-traffic hours. In a commercial network with various application scenarios, matching traffic load with an efficient energy-saving strategy is essential.

The basic energy-saving functions with multiple levels are designed for different coverage scenarios, times of day and traffic loads. The recommended strategy for the fundamentals is as follows.

1) **Symbol shutdown** can be scheduled at the millisecond level; thus, it can be applied to most scenarios even during medium traffic load. More power is saved under lower traffic loads. The function can remain activated all day.

2) **Channel shutdown** can be applied to a MIMO system during light traffic loads with the logical cell remaining without traffic handover. The power spectrum density of the remaining channels should be increased in order to ensure that the entire cell coverage is unaffected, especially for rural areas. The recommended traffic load is not more than 20% PRB utilization.

3) **Carrier shutdown** including intra-radio access technology (intra-RAT) and inter-RAT can be applied to multi-frequency or multi-mode network scenarios with co-coverage during extremely low traffic loads with regular traffic distribution. Users should be handed over to a basic coverage cell before the extra capacity layer is shut down. The recommended traffic load is not more than 10% PRB utilization.

4) **Deep sleep**: can be applied in multi-frequency and multi-mode networks during no traffic load especially in a 5G initial area to maximize the energy-saving efficiency. Users should also be handed over to basic coverage cell before equipment sleeps. Because more components are shut down during deep sleep, the activation time should be within 10 min.

8 Smart energy-saving solutions based on AI

8.1 Overview of AI technology

AI is the area of computer science focusing on creating machines that can engage on behaviours that humans consider intelligent. It combines computer science, physiology and philosophy that 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 research of AI programming techniques, the dream of smart machines is becoming a reality. Combined with the actual scale execution efficiency and effect, some mainstream AI models in the following list have been widely used.

a. Machine learning/machine learning library (ML/MLlib) (Spark), which can integrate ML with Spark in a simple, scalable and seamless way (ML mainly operates on data-frame, while MLlib operates on a resilient distributed dataset). These libraries can also be used in Python through PySpark.

b. Scikit learn is an open source library developed for ML. It is based on Python and designed on three other open-source projects: Matplotlib; NumPy; and SciPy. It focuses on data mining and data analysis, and contains a variety of tools for ML tasks.

c. TensorFlow is an open source machine-learning framework created by Google to support its research and product goals, which is easy to deploy on various platforms. The framework allows the development of neural networks and even other computational models using flowcharts. It can be encoded in C++ or Python and run on a central processing unit or graphic processor unit device.

d. Keras is an open source software library designed to simplify the creation of deep-learning modelling. It is written in Python and can be deployed on top of other AI technologies, such as TensorFlow.

e. PyTorch is a machine-learning library that provides a wide range of deep-learning algorithms. Torch is based on Lua and provides flexibility and speed for optimization.

A network intelligent solution based on AI is proposed after review of the research and application progress of AI in the cellular network field. The solution believes that AI can be introduced into a network on three levels: network element intelligence: operation and maintenance (O&M) intelligence; and service intelligence, with the principles of tiered, on-demand and phased. In this way, ubiquitous intelligence can be achieved.

Some leader operators have introduced intelligent capabilities into their network progress, e.g., O&M, network planning and optimization. According to Figure 1, 80% of operators hope that 40% of network intelligence will be realized, while one-third of them expect the rate will exceed 80% by 2025 [b-GSMA 2019b].

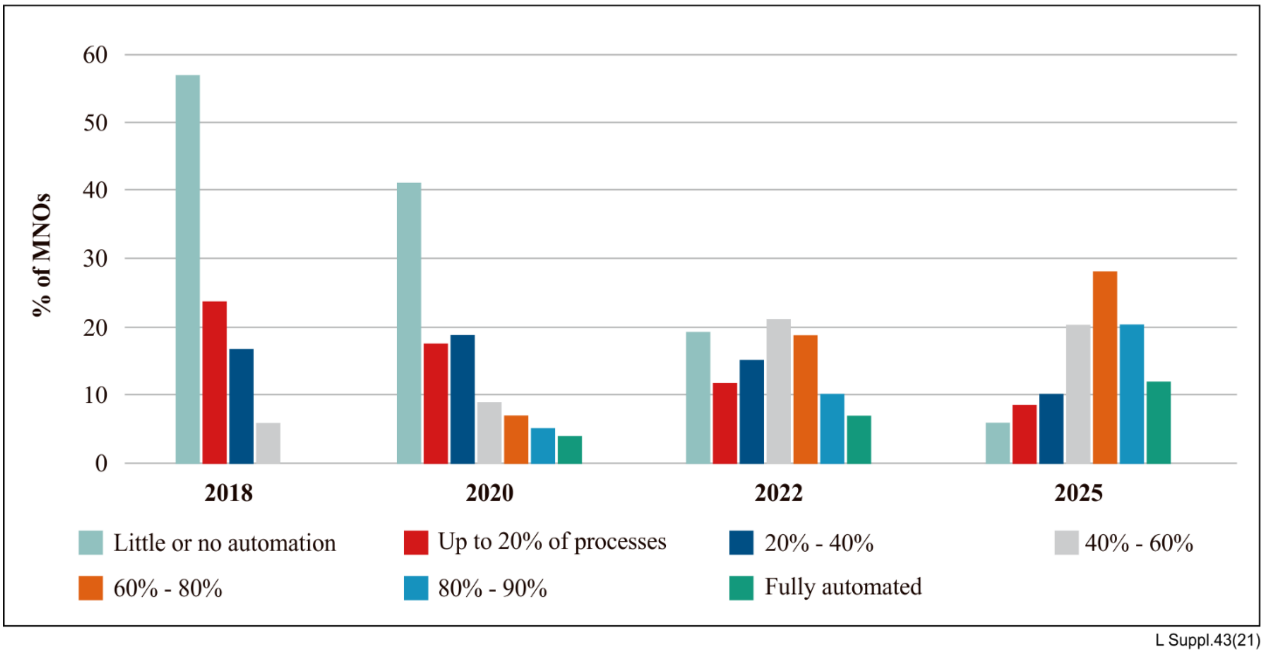

Figure 1 – Forecast levels of network automation by MNOs worldwide 2018-2025 (Source: Figure 6 of [b-GSMA 2019b] attributed to Analysys Mason)

In response to the requirement for an intelligent and self-adaptive energy-saving solution, AI and big data technology are also introduced into BS energy saving to improve efficiency and reduce the personnel required.

8.2 AI-based energy saving for 5G base stations

Nowadays, 5G network deployment is on a fast track around the world. Many MNOs are currently running second generation (2G), third generation (3G), 4G and 5G networks at the same time. The time distribution of cellular network traffic often has obvious peaks and troughs; the application of basic functions to the entire cellular network is not a site-specific strategy, resulting in lower efficiency due to overlooking the traffic and neighbouring site patterns that vary from site to site, especially in more complex networks.

In consequence, AI and big data technology have been introduced to form a more precise energy-saving strategy, based on specific site traffic and other site-related conditions. The AI-driven network energy-saving solution can forecast the traffic load of BSs based on historical traffic load, service type, site coverage and user behaviours. Energy-saving strategy can be configured automatically based on coverage identification and configuration identification by AI technology. A suitable energy-saving strategy combined with different energy-saving functions, including an initial threshold relevant to the scenario and executable energy-saving time schedule, is enabled for the sites that are expected to have energy-saving effects. At the same time, an AI-driven network energy-saving solution can also ensure balance between network power consumption and network performance based on appropriate model training.

The intelligent energy-saving scheme based on AI should include, but is not limited to, the following basic functions.

1. **Scene identification**: Based on historical traffic model analysis, the application scenario should be automatically identified, e.g., business district, residential area and high-speed train, thus more suitable initial energy-saving strategies are selected.
2. **Traffic forecast**: In most cases, the forecast matches well with actual traffic, which means that energy saving can be enabled on far more occasions. The modelling is based on historical traffic data (PRB utilization, RRC connected users, online users, throughput, etc.), special

days or holidays, user behaviour, etc. and then time series algorithms are applied to forecast traffic load.

3. **Multi-network coordinate control**: To achieve an efficient energy-saving strategy specific to a certain cell, the coverage of the cell and its neighbours, as well as 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 good availability of the neighbouring cell(s), including coverage and capacity. Thus, coverage identification depends on operating parameters (site identifier (ID), longitude, latitude, antenna height and azimuth) and measurement report (MR) data (cell ID, reference signal receiving power, signal to interference plus noise ratio, time advanced). Additionally, based on these information analyses, cell coverage performance can be calculated to identify the relationship between the co-coverage cells.

4. **Online iteration and optimization based on network performance**: In order to improve energy-saving efficiency, online iteration and optimization of the threshold can be used instead of traditional methods, which do not consider site variations, and result in safe but inefficient energy-saving settings.

8.3 Energy-saving scheme architecture based on AI

Figure 2 shows the overall architecture of an intelligent energy-saving network. Based on a wireless intelligent application platform, the AI algorithm is adopted to achieve maximum balance between system performance and energy-saving effect, so as to achieve network energy saving and consumption reduction.

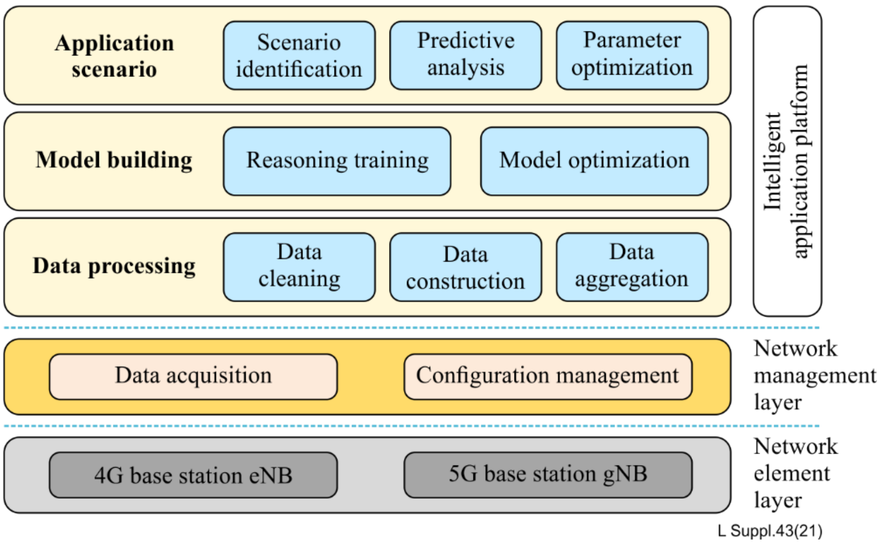

Figure 2 – Overall architecture of a 5G intelligent energy-saving network

By shutting down resources that are not utilized and maintaining adequate yet minimal network capacity, network energy consumption can be optimized in line with the network traffic load forecast driven by AI.

For the 5G era, enhanced AI-driven energy-saving solutions can take account of the different efficiency levels of frequency bands and factors, because the power efficiency of different networks can vary. By directing users from their less power-efficient spectrum band(s) to other band(s) that are more power efficient, more radio resources can be shut down to lower network energy consumption.

Alongside energy-saving potential, an AI-driven solution also can constantly monitor customer experience, network availability and data traffic to ensure there is no impact on network performance.

8.4 Recommended energy-saving procedure based on AI

As shown in Figure 3, an intelligent energy-saving procedure for a 5G BS is recommended as follows.

1. **Data acquisition**: Network performance data and MR or call detail trace (CDT) data are obtained from the BS through network management or a data acquisition system.
2. **Data processing**: The collected data are pre-processed by being cleaned, constructed, aggregated and screened as training data for scene recognition, load forecasting and other models.
3. **Scenario identification**: An ML algorithm is used to identify the application scenario and determine the energy-saving shutdown scheme and function.
4. **Threshold determination**: According to the energy-saving target to be achieved, an appropriate energy-saving threshold is determined.
5. **Time-span determination**: Based on historical traffic data, the ML algorithm is used to predict the traffic load in a certain period in the future to determine the energy-saving time and activate the time window.
6. **Execution strategy**: The integrated energy-saving strategy is sent to the network management system to perform the energy-saving operations on the 5G BS, e.g., deep sleep, carrier shutdown, symbol shutdown and corresponding activation time window.
7. **Feedback and optimization**: The performance data of the BS are collected to evaluate whether the expected target is achieved, and the closed-loop iterative optimization threshold strategy is adopted.

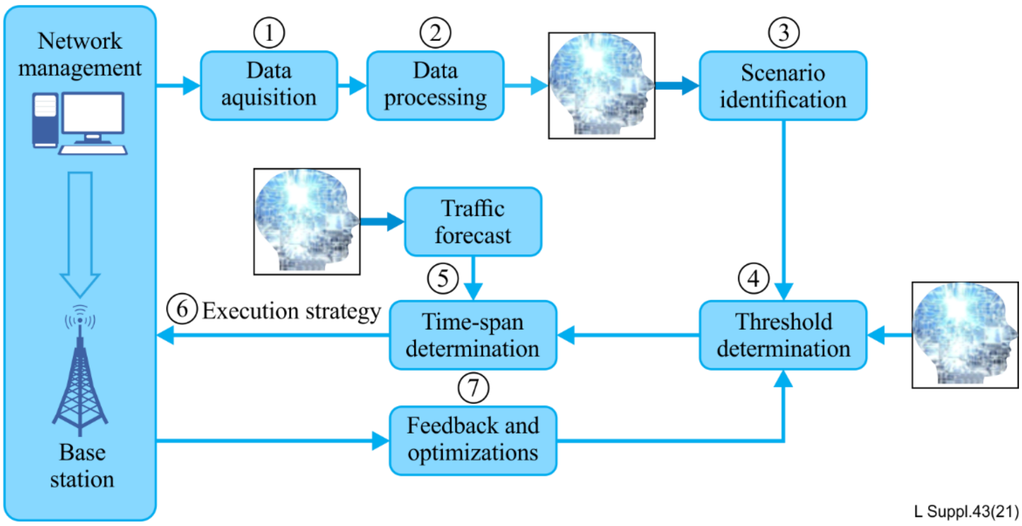

Figure 3 – AI energy-saving procedure for a 5G base station

8.5 Forecasting algorithms comparison in network traffic load

Two kinds of forecasting algorithm are often used in traffic load forecasting. One is a forecasting method based on sequence characteristics, including auto-regressive integrated moving average (ARIMA) mode, Prophet and other time series algorithms. Based on the characteristics of time series, this kind of algorithm breaks the time series down into periodic, trend and random disturbance parts, in order to model and predict. The second is the regression-forecasting method, including neural network, support vector machine and other regression algorithms. The regression model is established based on historical load data to forecast future load.

Compared with regression prediction, the time series algorithm is more suitable for stationary series and may have better operational efficiency. In a wireless network, the traffic load of most cells shows the characteristics of stationary series. The load forecasting value suitable for energy-saving algorithm accuracy can be obtained by using the prediction method based on series characteristics.

8.6 Service awareness energy saving for a 5G base station

An AI-driven energy-saving solution with traffic forecast improves the energy-saving efficiency of basic functions. However, in most multi-mode and multi-frequency cellular networks, it still has some limitations in that service efficiency varies from mode to mode or band to band. Additionally, if all services or users are concentrated in part of the network or band, more energy consumption can be saved after an idle network or band is shut down or put into deep sleep.

AI-driven service awareness in a 5G network should also be considered. Such service awarenesss exploits the differences in energy efficiency of various types of service to deliver certain services to the most energy-efficient network, helping achieve the most efficient energy usage without impact on user experience [b-GSMA 2020].

To improve network energy efficiency based on user redistribution, there are three main steps: target network or band selection; suitable user selection; and consequent user direction. Service efficiency varies from network to network or band to band, the most energy-efficient network or band is selected as the target and the most suitable users are selected. Also, energy efficiency patterns may change after user direction, leading to a new round of optimization.

Target network selection: The source network, band and target network or band identified here are clusters rather than cells, which can be selected based on coverage identification, traffic load forecast and energy efficiency analysis.

Suitable user selection: Since user experience can vary from network to network or from band to band, in order to guarantee user experience, user or service selection should be based on precise service identification, comprehensive user experience evaluation and specific business requirements.

Consequent user direction: The selected users, either in idle or connected mode, should be directed to the target network or band for user network or band distribution. User direction in coordination with other strategies, e.g., camping priority, mobility load balance and network or service slicing, should also be considered based on operator requirements.

9 Future prospects

Major vendors are currently offering AI-driven energy-saving solutions, and commercial application results show that activation time has been increased by 80% and over 10% (even 15%) of energy consumption has been saved over the entire network.

Network-wide intelligence is difficult to achieve overnight; long-term development is required. However, with the continuous accumulation of data from commercial networks, the ML algorithm will enable AI-based power-saving solutions to be perfected gradually. The AI algorithm itself will evolve iteratively to realize higher efficiency and accurate strategy adaptation when network topology and traffic model change.

The impact could be widened as follows.

1. Provision of feedback to the vendor industry to influence the design of more intelligent equipment that is more adaptive.
2. Development of consumer products, e.g., cell phones and cell phone software, that are more intelligent and can cooperate with the network in power and signal strength usage.
3. Design of vendor equipment to be more integrated with AI to reduce power usage.

5G network deployment has just started. Unlike existing 2G, 3G and 4G networks, which have all benefited from abundant data accumulation, there is a need in 5G to establish an initial power-saving strategy and its reference parameters and a power-saving collaboration between 4G and 5G networks.

These issues are under study and will be optimized as experience accumulates after the solution been widely deployed.

The Internet of things and enterprise network development are also contemporary big issues. With more carrier-level solutions being deployed in enterprises, along with services from different verticals, power-saving requirements on these scenarios will also be unique and complex compared to those of a cellular service network for the general public.

Bibliography

[b-ITU-T L.1361] Recommendation ITU-T L.1361 (2018), *Measurement method for energy efficiency of network functions virtualization*.

[b-GSMA 2019a] GSMA (2019a). *5G-era mobile network cost evolution*. London: GSM Association. Available [viewed 2021-09-09] at: https://www.gsma.com/futurenetworks/wiki/5g-era-mobile-network-cost-evolution/#

[b-GSMA 2019b] GSMA (2019b). *AI and automation: An overview*. London: GSM Association. Available [viewed 2021-09-10] at: https://www.gsma.com/futurenetworks/wiki/ai-automation-an-overview/

[b-GSMA 2020] Hatt, T., Kolta, E. (2020). *5G energy efficiencies: Green is the new black*. London: GSM Association. Available [viewed 2021-09-10] at: https://data.gsmaintelligence.com/research/research/research-2020/5g-energy-efficiencies-green-is-the-new-black

[b-de Garis] de Garis, H. (2005). *The artilect war – Cosmists vs. terrans – A bitter controversy concerning whether humanity should build godlike massively intelligent machines*. Etc Pubns. 254 pp.

[b-Mayer-Schönberger] Mayer-Schönberger, V., Cukier, K. (2013). *Big data: A revolution that will transform how we live, work and think*. Boston, MA: Houghton Mifflin Harcourt. 242 pp.

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, 2021