Future Green Mobile Communication Technology Facing the "Double Carbon" Goal

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Abstract. The goal of "double carbon" (namely "peak carbon dioxide emissions" and "carbon neutrality") proposed by China for the first time is an important layout in the Tenth Five-Year Plan, and it is also the key goal to realize the green and sustainable development of mobile communication networks in the future, and it is also the foundation for China's international carbon asset pricing right and the world carbon trading platform. Among them, the difficulty in realizing green communication lies in maintaining the growth of business volume. Reduce network energy consumption and carbon emissions. This paper studies the green communication technology from the perspective of energy saving and emission reduction on the mobile communication network side and the perspective of the integrated architecture of communication network and multi-energy energy network. The research results show that the key to realize green communication technology lies in the mutual matching of network resources, energy resources and business distribution, while the existing technology can only achieve one-way matching of network resources and business distribution. Or the one-way matching of energy resources and service distribution. Based on this, this paper proposes a native green grid architecture with communication, perception and energy fusion, which has the ability of energy perception and service perception, supports the two-way matching method of network resources, energy resources and service distribution, and realizes the continuous growth of service while significantly reducing the energy consumption and carbon emissions on the mobile communication network side by eliminating the randomness and suddenness of service distribution and energy distribution.

1 introduction

In order to cope with the increasingly severe climate problem and meet the third global energy revolution, China, as the largest developing country in the world, took the lead in proposing the "double carbon" goals of "peak carbon dioxide emissions" and "carbon neutrality". During the long-term evolution of mobile communication networks, Always follow the vision of green communication. How to ensure the personalized service quality of users while the total energy consumption and carbon emissions of the network are greatly reduced has become one of the challenges facing the future mobile communication network. However, the existing mobile communication network has the problems of high energy efficiency, high waste and high carbon emissions, so it is necessary to study the future green mobile communication technology from the perspective of the integration of communication network and energy network.

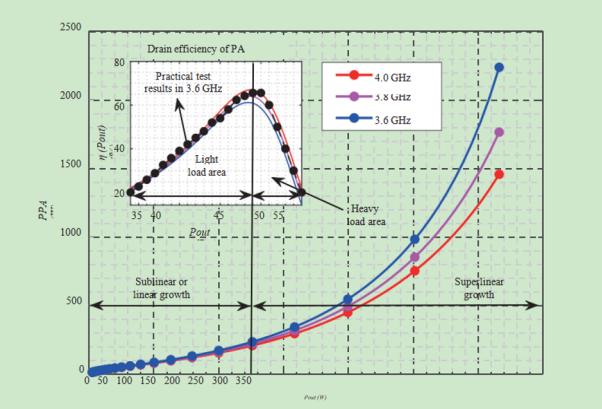

Fig. 1 (Network Color Map) Nonlinear Curve of Amplifier
Figure 1 (Color online) Nonlinear mapping of power amplifier

1.1 Opportunities and Challenges of Future Mobile Communication Networks

In the future, mobile communication networks will meet the differentiated performance requirements of different services. Based on the three service

scenarios of the 5th Generation Wireless Communication Networks (5G), namely, large-scale machine communication services, high-reliability low-delay services and mobile broadband services, The international mobile telecommunications (IMT) promotion group proposed six business scenarios of the 6th generation wireless communication networks (6G). Including immersive communication services, ultra-large-scale communication services, ubiquitous connection services, extremely reliable low-delay services, integrated communication awareness services and artificial intelligence, AI)-communication integration services [1]. The ultimate performance of the future network seems to bring infinite possibilities to all mankind. However, under the trend of "sustainable development", It still faces difficulties and challenges. According to the forecast of China Unicom, in 2020-2030, the number of base stations of domestic operators will increase by 9.6 times, the energy consumption and carbon emissions will increase by more than 8 times, and the cumulative carbon emissions will increase by 590 million tons, which runs counter to the concept of "sustainable development". In order to achieve the goal of peak carbon dioxide emissions in the future, the carbon emissions of mobile communication networks at that time should be consistent with the current carbon emissions. In other words, in the future, mobile communication networks need to provide nearly 100 times of traffic under limited energy constraints, so as to improve energy efficiency by 10,100 times. In addition to the problems of high performance and high indicators, future mobile communication networks are also faced with the problem of super-linear growth of carbon emissions with the growth of business volume, especially in ultra-high data density business scenarios. The traffic carried by the network changes randomly in the space domain and time domain, and is influenced by the nonlinear effect of each module of the base station, which inevitably leads to the generation of extra energy consumption and extra carbon emissions. Among them, the nonlinear mapping between the input power consumption and the output power consumption of the radio frequency amplifier of the base station is one of the main factors that cause high carbon emissions and high frequency energy consumption, as shown in Figure 1. Therefore, It is one of the important scientific problems that mobile communication networks will face in the future to clarify the cognitive ambiguity of the relationship among carbon emissions, network carrying capacity and service distribution. Driven by this problem, domestic and foreign research institutions have successively carried out research on green communication technology.

Table 1 Current research on "carbon-peaking and carbon-neutrality" target in Chinese communications industry

Research Report/White Paper of Equipment Manufacturers/Operators/Research Institutions Ideas and Schemes of Energy Saving and Emission Reduction		
Huawei Green Development 2030 [2]		Minimalist architecture: It is realized by the minimal architecture of basic network, cloud network and computing network.
ZTE Green 5G Core Network White Paper [3]		Low carbon network; Photoelectric hybrid: the integration of photoelectric technology will bring about profound changes in communication network equipment architecture and energy efficiency.
China Mobile China Unicom	China Mobile peak carbon dioxide emissions Carbon Neutralization Action Plan White paper [4] China Unicom 5G intelligent energy-saving technology white paper [5]	The new model of "4+3+2" architecture, on the one hand, realizes the green 5G core network to reduce the energy consumption of operators' network infrastructure, on the other hand, acts as a green enabler, and helps the country achieve the goals of "peak carbon dioxide emissions" and "carbon neutrality" on the basis of meeting the green transformation needs of industry users. Construct a new green developmentmodel of"three energy and six green", in which "three energy" refers to Energy saving, energy clearing and empowerment, "six greens" refers to green grid, green energy use, green supply chain, green office, green empowerment and green culture. The "3+5+1+1" action plan aims at establishing a carbon management system, Focusing on the direction of green development, we will promote the co-construction and sharing of infrastructure and empower all walks of life to save energy and reduce carbon.
China Telecom China Telecom peak carbon dioxide emissions Action White Paper [6]		"1248" Double Carbon Action Plan integrates the concept of green and low carbon into network regulations. Planning, construction and operation of the whole process, focusing on low-carbon, zero-carbon and negative-carbon technologies, and fully realizing green and low-carbon development.
IMT-2030(6G) propulsion group	6G Overall Vision and Potential Key Technologies White paper [7]	Driving forces or environmental sustainable development: reducing carbon emissions and promoting "carbon neutrality" It is required to improve energy efficiency and realize green development.
5G Evolution Academic Exchange Forum	White paper on key technology vision of energy saving and emission reduction for 5G-A/6G wireless communication system [8]	Establish a sound energy efficiency evaluation standard and system for wireless communication systems, and develop energy-saving technologies at link level, site level and network level. Enable other industries to save energy and reduce emissions.

1.2 Research status and conclusion of green communication technology at home and abroad

In order to actively respond to the implementation of the national "double-carbon" goal, China's communication equipment vendors and operators have put forward corresponding ideas and schemes for energy saving and emission reduction from different levels of communication systems, as shown in Table 1 [28]. China Mobile, China Telecom and China Unicom have issued their own white papers and action plans for the "double-carbon" goal. It is expected to achieve the effect of saving electricity and reducing carbon emissions by optimizing the deployment of communication networks and communication facilities. From the perspective of systems and architecture, Huawei, ZTE and other communication equipment vendors put forward a new network architecture oriented to low energy consumption, and make full use of AI enabling technology to reduce the energy consumption of core networks and access networks. Academics put forward the development direction of green communication technology from the theoretical level and predicted related indicators. For example, the IMT-2030 Promotion Group proposed that the energy efficiency of the next generation mobile communication network should reach 10,100 times as much as it is now. At the same time, the research on green communication technology in foreign academic circles and industries is gradually carried out. See table 2 [914]. The Alliance for Telecommunications Industry Solutions (ATIS) and the European Telecommunications Standards Institute (European Telecommunications Standards Institute, ETSI) regards green sustainable development as one of the goals to be achieved in the next generation communication network. Heta-x, the flagship project of 6G in Europe, thinks that "sustainable development" is one of the three cornerstones of 6G network, and the International Telecommunication Union (ITU) has planned the application scenario of green communication in "IMT towards 2030 and beyond".

The above research results show that sustainable development will be the only way for the future evolution of mobile communication networks, and the research on green communication technology will not only affect the evolution of the next generation of mobile communication networks, but also affect the development trend of the community of human destiny. Through research, this paper explores the capacity boundary of energy saving and emission reduction of mobile communication systems, that is, whether the future mobile communication networks can reduce energy consumption by 50% while ensuring users' differentiated service quality requirements. The carbon emission is reduced by 50% [8]. The follow-up content of the article is organized as follows. Section 2 expounds the low-carbon evolution direction of green communication technology facing the goal of "double carbon", including network structure flexibility, transmission unit simplification, network resource diversification and communication energy integration. Section 3 investigates the green communication technology in the existing mobile communication network from three angles: networking technology, transmission technology and resource management technology. The research conclusion shows that the existing green communication technology can reduce energy consumption by more than 50%, but it can't reduce carbon emissions by 50% under the same and limited energy constraints. In section 4, based on the mobile communication network, the energy network is introduced, and the low-carbon emission technology under the linkage of communication network and energy network is studied. By comparing several different architectures, the feasibility of dual-network integration architecture for reducing carbon emissions by 50% is confirmed.

Table 2 Current research on the "sustainable development" target in foreign communications industry

Operator/Equipment Vendor/Research Institute	Research Report/White Paper Concept and Scheme of Energy Saving and Emission Reduction	
ATIS	Green G: the path toward sustainable 6G [9]	Next generation network Green G, sustainability is One of its six goals is to fundamentally change the way of supporting the next generation of communication and computer networks with electricity, and at the same time strengthen the role of information technology in protecting the environment.
Hexa-X	Designing the 6G networks of the future [10]	Sustainability is one of the three cornerstones of 6G, and the goal is to optimize the digital foundation. Facilities can save energy and reduce consumption, effectively reduce greenhouse gas emissions, and provide efficient and sustainable digital tools for industry, society and decision makers.
ITU	IMT towards 2030 and beyond [11] The fifth generation fixed	6G users and applications will present nine trends, such as ubiquitous intelligence, ubiquitous computing, immersive multimedia and multi-sensory communication, digital twinning and expanding the world, intelligent industry, digital medical care and health, ubiquitous connection, integration of perception and communication, and sustainability.
ETSI	network: bringing fibre to everywhere and everything [12]	Reducing carbon emission through green technology is the key to reduce the ecological impact of communication industry. The energy consumption of the network itself should be managed as much as possible. Reduction. With advanced F5G technology, energy efficiency can be directly improved by transitioning to a more efficient F5G advanced optical network in communication systems and data centers.
Qualcomm	The future AI is hybrid [13] 6G spectrum: enabling the future	Combining AI technology with 5G, hybrid AI flexibly distributes load 5G Provide efficient connection. Use hybrid AI architecture to optimally allocate resources, energy consumption and computing power between terminal and cloud.
Ericsson	mobile life beyond [14]	Minimize the environmental footprint of ICT industry, while maximizing the positive role of current and future mobile networks. Transformation from efficiency to sustainability: a high resource efficiency network that affects society and reduces environmental footprint through effective digitalization.

Section 5 looks forward to the future work and challenges, and section 6 summarizes the full text.

2 Low-carbon evolution of mobile communication network

In the initial stage of mobile communication network deployment, in order to improve the coverage of network signals as much as possible, operators adopt the strategy of deploying high-power base stations with regular hexagonal coverage to form homogeneous cellular networks with regular structure and uniform density. With the further development of mobile communication network, the single-layer network composed of a single Hong Fengwo base station can no longer meet the diversified and differentiated needs of users' services. Hong Fengwo coverage and microcellular blind compensation have become an effective deployment method to improve network service capacity; In order to further realize the deep coverage of the network, operators have adopted intensive deployment of micro-base stations to improve the network coverage capacity, and the number of base stations and antennas per unit area has surged, which has brought explosive growth in carbon emissions and energy consumption while improving the network service capacity. Facing the goal of "double carbon", the mobile communication network is evolving towards low energy consumption, high energy efficiency and low carbon emissions, which is embodied in the following four aspects:

The network structure is flexible, and network density is one of the most direct and effective ways to improve network capacity. However, network density does not always improve network performance. On the one hand, the complex interference between cells in ultra-dense networks will worsen network performance, on the other hand, the increase of base station density will simultaneously bring about the increase of carbon emissions. Obviously, dense and seamless coverage is not a low-energy coverage method. Considering the randomness of business traffic distribution in the network, It is an energy-efficient and low-carbon coverage scheme to match the network structure and service distribution through the elastic change of networking architecture and realize on-demand coverage.

Simplification of transmission units, with the growth of streaming media services, the number of terminal connections and traffic per unit area has surged, and the number of antennas at the transceiver end of the base station RF module has increased, gradually evolving from the traditional single antenna structure to the multiple-in and multiple-out (MIMO) structure. However, due to the nonlinear effect of RF devices, ultra-large-scale antenna arrays will lead to the coexistence of high energy efficiency and high energy consumption, and the thinning of transmission units is an effective way to reduce carbon emissions. Under light business load, antenna/symbol/carrier can periodically sleep and turn off, which can reduce power consumption while maintaining the service capacity of base stations.

Network resources are diversified. In the two-layer heterogeneous network composed of Hong Fengwo base station and microcellular base station, interlayer interference seriously restricts the energy efficiency of the network. How to effectively manage and control communication resources, eliminate cross-layer interference and improve network energy efficiency has become one of the evolution directions of mobile communication networks towards low-carbon development; In the mobile communication network, in addition to wireless resources such as carrier, bandwidth, symbols and time-frequency resource blocks, energy resources such as electricity and photovoltaic, it also includes physical resources such as network infrastructure and virtualized functional entities, as well as sliced resources composed of virtualized functional entities. Reasonable and efficient management and control of these resources can effectively reduce network energy consumption and carbon emissions.

Communication energy integration, in order to meet the demand of improving the energy efficiency by 10100 times in the future mobile communication network and realize the goal of carbon neutrality at the same time,It means to guarantee the quality of service for users under the limited carbon emission or energy constraints. Integrating mobile communication network with green energy network is a feasible scheme to achieve the above objectives. Green energy network can collect clean energy such as solar energy, wind energy and tidal energy. The difference from traditional power grid is that green energy network will not produce carbon emission, and the electricity price of clean energy is lower than that of traditional power grid. Therefore, the integration architecture of mobile communication network and green energy network will become an inevitable choice to achieve the goal of low carbon emission or even zero carbon emission.

To sum up, facing the goal of "double carbon", on the one hand, the mobile communication network is evolving towards low energy consumption, and the energy consumption on the network side is reduced through networking technology, transmission technology and resource management and control technology; On the other hand, it is evolving towards the integration of communication network and energy network, and reducing carbon emissions through on-demand scheduling, sharing and trading of energy resources. Based on this, this paper investigates the

low-energy technology in mobile communication network (Section 3) and the low-carbon emission technology under the integration framework of mobile communication network and energy network (Section 4) respectively.

3 Low-carbon-oriented networking transmission technology

As the energy consumption side, reducing the energy consumption of mobile communication network is the most direct means to reduce carbon emissions and improve network energy efficiency. Combining with the low-carbon evolution direction of mobile communication network, this section mainly studies the energy-saving technology in mobile communication network from three aspects: networking technology, transmission technology and resource management technology.

3.1 networking technology

The network structure determines the coverage ability of the network. From the early signal coverage and capacity coverage to the current deep coverage and wide-area coverage, and the global and seamless coverage for the future mobile communication network, the network structure has changed from isomorphism to heterogeneity, from two-dimensional plane coverage to three-dimensional coverage, from uniform and regular hexagonal honeycomb structure to dense and disordered Tai Sen polygon structure. Facing the goal of "double carbon", The mobile communication network structure should realize low-carbon, sustainable, energy-efficient and on-demand coverage matching the service distribution. This section will review several energy-efficient network coverage structures in long term evolution, LTE) and new radio, NR) of 3G, and describe their energy-saving mechanisms, as shown in Table 3 [1523].

3.1.1 Centralized RAN structure

Centralized/cloud-radio access network (C-RAN) is an access network structure proposed in reference [15], as shown in Figure 2. C-RAN structure is composed of baseband unit, BBU) and remote radio head, RRH) separately arranged from the former. Among them, a certain number of BBUs are centrally deployed to form BBU pool. In C-RAN, virtualized BBU pool can uniformly manage and dynamically allocate baseband processing resources, that is, it can adapt to non-uniform services and improve resource utilization, and through the cooperation between baseband processing units, it can optimize network performance and reduce operating costs [16].

Compared with 4G C-RAN, 5G C-RAN continues the main features of centralization, collaboration, cloudization and green, and at the same time, it has produced some technical evolution on the basis of 4G C- RAN. 5G C-RAN divides the baseband processing unit into central unit, CU) and distributed unit (Distributed Unit, DU), and put forward the concept of logical two-level concentration. The first level concentration can introduce coordinated multiple points transmission (COMP) and distributed multiple-in-and-out (distributed multiple-in-and-out).

Multiple-out, D-MIMO) and other technologies, in order to improve the cell edge spectrum efficiency and the average throughput of the cell, and overcome the problem that base stations between different resource pools in 4G C-RAN cannot provide services for border users through joint transceiver, which brings "signals without services". At the same time, By adopting the next generation forward interface (NGFI) and network functions virtualization (NFV) architecture, resources can be reused and shared to the greatest extent, and functions can be flexibly deployed. Respond to the "tidal phenomenon" in which the business changes dynamically with time. Because of its characteristics of wireless cloudization, centralized deployment and cooperation, 5G C-RAN reduces its dependence on the wireless computer room, reduces the construction cost and overall power consumption of the computer room, reduces carbon emissions, and realizes green and energy-efficient communication. In addition, it can also combine the C-RAN structure with AI algorithm. Further energy saving can be achieved by matching service distribution with resource distribution. Literature [17] designs a C-RAN structure based on Markov calculation model, and formulates a BBU active/sleep state transition scheme under dynamic RRU traffic load, which realizes energy saving under dynamic traffic load. Reference [24] proposes semi-static and adaptive BBU-RRH handover schemes, which can reduce the number of BBUs by 26% and 47% respectively compared with traditional cell deployment [17]. Both methods realize the mutual adaptation of service distribution and coverage structure, thus effectively reducing system energy consumption.

Table 3 Comparison of access network structures

Main characteristics, shortcomings/problems to be overcome of coverage structure type		
C-RAN[15-17] Supercell[18,19]	(1) Baseband processing unit and RF unit are arranged separately. In this way, the baseband processing units are centralized in BBU pool, and the resource utilization efficiency is improved through cooperative operation between base stations; (2) 5G C-RAN divides the baseband processing unit into two functional entities, CU and DU, and uses NFV and NGFI structure realizes flexible deployment of functional units and improves resource reuse rate.	NGFI structure supports both complete centralized deployment and distributed DU deployment, among which, complete centralized deployment is difficult to provide services for border users through joint transceiver, and there may be a phenomenon of signal without service at the border; However, the operating cost of distributed DU deployment is relatively high.
	(1) Flexible coverage is achieved by moderately separating control coverage from service coverage; (2) elastic matching of resources and energy distribution; (3) According to different types of services and user needs, provide appropriate services according to needs.	Flexible coverage, flexible access and moderate service mechanisms to improve energy efficiency will bring extra time and reduce user experience. How to balance network energy efficiency and service delay becomes a big challenge.
Cell-Free coverage structure [2022] uplink and downlink adoption	(1) Each user is served by an access point cluster composed of multiple access points at the same time. Because users are close to access points, the coverage rate is improved; (2) The access point serves users through time division duplex, without cell boundary; (3) Conjugate beamforming/matched filtering technology improves the system. Throughput of; (4) Maximum/minimum power control algorithm is adopted to ensure the same and high-quality service for the whole coverage.	The complexity of implementation is high. Compared with the small cellular system,
Honeycomb-free large-scale MIMO		The system needs more return trips.
Resource cell [23]	(1) Energy coverage mode of on-demand coverage: periodically adjust the network by analyzing the space-time evolution law of service distribution. Topology; (2) Switching-off/activation strategy of network elements matching the coverage structure: Access points in the cell can switch off and activate CU/DU network elements according to the network topology; (3) User-oriented Carrier dormancy and transmission mechanism of the center: CU network element for each	Minute-level adjustment of transmission link in resource cell coverage structure can realize accurate matching between coverage and service, But it is difficult to meet the microsecond change of channel state,

3.1.2 Superpeak nest covering structure

In order to adapt the cell coverage to the service structure, provide the service on demand, and realize flexible coverage, a super-cellular network architecture [18] with partial control signaling function decoupled from data function can be adopted, as shown in Figure 3.

Supercell is a network architecture with co-optimized resources and energy efficiency, which is different from the traditional cellular network with coupled services and signaling. It was first proposed in literature [19]. The main feature of the femtocell network architecture is that it adopts a way of moderately separating control coverage from service coverage. Under the condition of low load, only a small amount of energy is used to maintain control coverage, and service coverage can be dynamically allocated according to actual service requirements, thus realizing flexible coverage [19]. Based on this, the femtocell can be started according to actual needs.

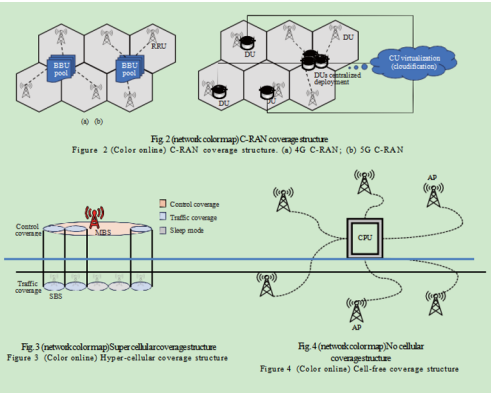

Fig. 2 (network color map) C-RAN coverage structure
Figure 2 (Color online) C-RAN coverage structure. (a) 4G C-RAN; (b) 5G C-RAN

Fig. 3 (network color map) Super cellular coverage structure
Figure 3 (Color online) Hyper-cellular coverage structure

Fig. 4 (network color map) No cellular coverage structure
Figure 4 (Color online) Cell-free coverage structure

The traditional cellular network has the problem of control signaling covering holes due to the introduction of base station dormancy [19]. And by jointly optimizing the service base station dormancy and spectrum allocation, the super-cell can save 50% of network energy consumption in typical scenarios [18]. Literature [25] studies the service base station dormancy in the super-cellular network under the bursty service arrival model, and quantitatively analyzes the influence of the service base station dormancy mechanism on the service delay. The optimal base station sleep scheme is designed under the delay constraint, and the influence of service burstiness on the system energy efficiency is fully considered, so as to further optimize the system and reduce power consumption. The service flow and resource flow are efficiently matched to realize low-energy green communication. In addition, the document [18] proposes a software-defined super-cellular network architecture, which consists of two parts, namely, virtualized infrastructure and software-defined services. By adjusting the size of the virtual base station pool, the gains and losses can be calculated before and after.

3.1.3 Honeycomb-free coverage structure

Cellular-free network structure is a new network structure that conforms to the trend of green communication [26], and it is called "cellular-free" because it has no cell edge of traditional cellular structure, as shown in Figure 4. The architecture is user-centered and consists of a large number of access points (AP) and centralized processing unit (CPU). CPU). Each user in a cellular-free network is served by an access point cluster consisting of a plurality of specific access points [21,22]. Access points jointly serve users on the same time-frequency resources through time division duplexing, TDD) mode. Because the selected access point is close to users, the path loss is small. Therefore, it is possible to reduce the transmission power of the radio frequency band on the premise of meeting the communication quality requirements of users, thus improving the system energy efficiency. However, the energy resources without cellular network structure may be inefficiently utilized. For example, during the period of low traffic load, if all access points in the cellular network remain on, the utilization of resources does not match the service demand, which will lead to energy waste.

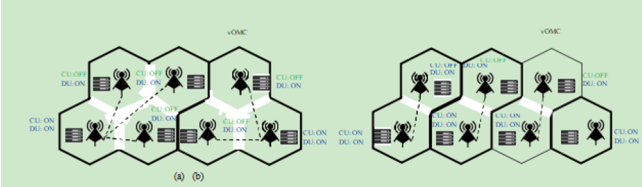

Fig. 5 (Network Color Map)Resource Cell Coverage Structure
Figure 5 (Color online) Resource cell coverage structure

In order to build a green communication network, in the future, cellular-free large-scale MIMO networks will develop in the direction of intelligence, and combine with artificial intelligence algorithms to further improve energy efficiency and reduce carbon emissions. Specifically, reference [27] proposed a strategy to dynamically turn on/off some access points according to the number and location of active mobile stations in the network. By balancing the available network state information and hardware configuration (that is, the number of access points, the number of transmitting antennas and the number of mobile stations in each access point), the matching between resource flow and traffic flow is realized. Similarly, reference [28] studies the sleep energy-saving mechanism of access point AP in time-varying channel environment, compares the AP switching strategy to a markov decision processes, and dynamically adjusts the AP switching problem through deep reinforcement learning algorithm to meet the user's business demand and realize energy-efficient communication.

3.1.4 Resource cell coverage structure

In order to make the network structure adapt to the space-time distribution of services in the network in time, and at the same time meet the requirements of high energy efficiency and on-demand coverage in ultra-high data density service scenarios, reference [23] proposed a resource cell coverage structure, which evolved on the basis of 5G C-RAN structure and followed 5G NR centralized unit, distribution unit and activated antenna unit. AAU) three-level separation structure, adopts service-based architecture (SBA) with data plane and control plane decoupled, supports flexible networking and multi-point cooperative transmission, and accesses the virtual operation and maintenance center (Virtual Operation and Maintenance Center) on the network side. VOMC) can generate network topology, manage and arrange network structure, distribute CU-DU mapping table to resource cells, guide coverage structure adjustment, achieve seamless coverage of signals and capacity on demand according to dynamic changes of services, and match coverage structure and service distribution, as shown in Figure 5. The energy-saving mechanism of resource cells has the following three points.

(1) Low-energy energy coverage mode: Different from capacity coverage mode, energy coverage is aimed at the "tidal" phenomenon of business changes in ultra-dense networks under limited energy constraints or carbon emission constraints. Resource cells periodically adjust the network topology and reconstruct the coverage structure by analyzing the space-time evolution law of business distribution. For example, in areas with high demand for mobile terminals, the network is centered on user clusters. Cluster adjacent access points with strong channel correlation to form a resource cell, and the access points in the cell cooperate to transmit signals for users in the cluster, thus enhancing the useful signal gain of the user terminal, thereby improving its signal-to-interference and noise ratio; In areas where the traffic demand of mobile terminals is small or even zero, resource cells adopt different levels of dormancy, including network level, site level, network element level and carrier level. The strategy of dormancy is implemented by centralized units in the resource cells, which ensure the seamless coverage of network signals in the global scope to facilitate the transmission of control signals.

(2) Switching-off/activation strategy of network elements matching the coverage structure: Thanks to the 5G NR AAU-DU-CU separation structure, after the resource cell is formed, the access points in the cell can switch off and activate the CU/DU network elements according to the network topology. Among them, one resource cell only activates the CU network elements of one access point. The remaining access points only activate the DU network elements and turn off the functions of the CU network elements at the same time. The activated CU network elements are responsible for the CU functions of all access points in the resource cell, and exchange information with the DU through the middle transmission link. On the one hand, the resource cell can save energy by turning off a large number of access point CU network elements, on the other hand, the activated CU network elements can centrally control the AAU transmission power in the resource cell and allocate wireless resources, thus achieving efficient energy utilization.

(3) User-centered carrier dormancy and transmission mechanism: In the 5G NR transmission technology defined by 3GPP, very large-scale multi-input

Mass Multiple-in and Multiple-out (Mass-MIMO) technology supports beam directional transmission, and access points can allocate orthogonal carrier beams for users to enhance coverage. In resource cells, in order to maintain the orthogonality of carriers used by users in the cluster and avoid interference caused by the same frequency transmission, CU network element strictly allocates available orthogonal carriers to each access point, and periodically activates and sleeps different carriers to avoid co-frequency interference between adjacent cells. Under this mechanism, the resource cell can reduce the transmission power of the RF terminal by at least 50%. In order to overcome the problems of high energy consumption and high carbon emission caused by the nonlinear input and output power of the RF terminal, the resource cell supports the following three kinds of energy saving.

Technology:

(1) Flexible networking technology: For diversified business requirements, resource cells can dynamically adjust the coverage structure through flexible networking. For ultra-high data density traffic scenarios, multiple cells are merged, which enables cooperative transmission between access points to enhance coverage capacity and reduce the average energy consumption of access points. For large-scale connection scenarios, resource cells are split and provide services to users in energy coverage mode.

(2) Dynamic dormancy technology: In order to reduce the extra energy consumption during the idle period of base stations, resource cells support various levels of dormancy. For areas with low traffic demand and low traffic density, resource cells support carrier-level, device-level, site-level and cell-level dormancy, and realize on-demand coverage by actively generating coverage holes.

(3) PA voltage regulation technology: the energy consumption of RF unit mainly depends on the bias voltage, which is positively related to the BS load. Therefore, after the resource cell is generated by elastic networking, the access points in the resource cell are selectively associated with the user equipment. By keeping the RF unit working in the linear region, the bias voltage can be reduced, thus significantly reducing the RF energy consumption.

1.2 Transmission technology based on turn-off design

According to statistics, about 65% of the energy consumption of the base station is generated by the radio frequency unit in the process of amplifying the transmission signal, and the fundamental reason for the high energy consumption of the radio frequency unit lies in the nonlinearity of the radio frequency device. Therefore, adopting a simplified beam design to keep the radio frequency device working in the linear region is an effective way to reduce the power consumption of the device. Unlike deep sleep, the simplified beam design is a short period and shallow sleep of microseconds to seconds. The base station can transmit control signals sparsely according to the change of service, which can ensure continuous coverage on the space-time scale of the base station and reduce the energy consumption of the base station, including three dimensions: spatial domain (antenna off), time domain (symbol off) and frequency domain (carrier off).

3.1.5 Spatial domain design-antenna off

Compared with 4G base stations, the number of channels in 5G base stations is significantly increased. In order to match the service load, multi-antenna channel shutdown can be considered under the condition of less service demand, thus reducing carbon emissions and saving energy. Compared with symbol shutdown, Channel shutdown has more advantages in ensuring service continuity [29]. Channel shutdown refers to dynamically deciding to open/close channels to save energy consumption by judging the utilization rate of physical resource block, PRB), the number of users connected by radio resource control, RRC) and the number of voice users in the corresponding cell. Under the condition of low load, some antenna channels in this cell are allowed to be closed. In order to ensure that the coverage and service of the control channel are not affected and the user experience is not reduced after the channel is closed, the method of reasonably increasing the transmission power of the remaining channels can be adopted to solve the problem that the total transmission power and antenna gain are decreased after the channel is closed. Until the user's service demand is increased, the original channel number and channel transmission state are restored. The antenna closing operation matches the service demand, effectively coping with the uneven distribution of services in time.

3.1.6 Time Domain Design–Symbolic Turn-off

Symbol turn-off was first proposed in 4G LTE system. In order to save power overhead, symbol turn-off can be carried out when there is no service in the case of medium and light load. The scheduler can allocate a certain number of symbols for downlink data according to the

system load and service data prediction, and turn off the power amplifier, PA) when there is no information transmission. Especially, You can turn off the symbols without cell reference signal, CRS), synchronization signal, SS) or broadcast information. Match the symbol turn-off with the service flow, and you can predict that PA power amplifier will be turned off at the symbol time when there is no effective information transmission, or a small amount will be used.

User data scheduling is concentrated in several time slots, and the power amplifiers in the remaining time slots without user data transmission are turned off, so that the energy-saving benefits of symbol turn-off can be obtained in a larger time range to reduce system energy consumption. The essence of symbol turn-off energy saving is to reduce the static power consumption of power amplifiers. If X symbols are turned off, the static power consumption of power amplifiers and transceiver units can be reduced by X/14 [29].

3.1.7 Frequency Domain Design–Carrier Shutdown

Carrier turn-off refers to turning off some carriers to achieve common coverage under the condition of extremely low traffic load and irregular traffic distribution, which is suitable for multi-frequency or multi-mode network scenarios. Carrier turn-off can be divided into intra-system carrier turn-off (LTE system or NR system) and inter-system carrier turn-off (4G/5G cooperative carrier turn-off). One layer is used as the coverage layer and the other layer is used as the capacity layer. Under the condition of low cell load, Turn off the capacity layer and keep the coverage layer [29]. Users should hand it over to the basic coverage cell before the capacity outer layer is turned off, and the traffic load usually does not exceed 10% of the utilization rate of physical resource blocks.

3.2 Resource management and control technology

In the mobile communication network, in addition to reducing energy consumption by matching the network structure with the service distribution, it is also an effective method to reduce carbon emissions by matching the network resources with the service distribution in different dimensions through resource management and control technology. The network resources here include communication resources, such as network resources such as core network functional entities and base station data units, computing resources such as computing power and AI model, and storage resources.

3.2.1 Communication resources

Network slicing is the key technology in the application scenario of 5G large-scale industrial Internet of Things [30]. Network infrastructure resources can be sliced according to different business types, and network resources, such as computing resources, communication resources and cache resources, can be provided according to business requirements. Facing the goal of "double carbon", low-carbon and green network slicing technology still needs to be studied. This paper proposes a low-carbon network slicing architecture, as shown in Figure 6. Similar to typical network slicing architecture, this architecture includes virtualized network infrastructure (NFVI), low-carbon network slicing and network slicing management and orchestration (MANO).

Virtualized network infrastructure is obtained by virtualizing all kinds of hardware resources of low-carbon network architecture, including computing, communication, storage and sensing functions. Virtualization of network functions can make network slicing more flexible, diverse and extensible. By virtualizing all kinds of resources in the network, different virtual network functions can be provided to low-carbon network architecture, which are interconnected to form a complete business function chain and provide customized services for end users.

In the low-carbon network architecture, the common functions include carbon emission measurement, energy scheduling and energy sensing [31], and the corresponding slices include carbon emission measurement slice, energy routing slice and energy sensing slice. Carbon emission measurement slice is used for real-time monitoring of carbon emission in the network, detecting abnormal carbon emission areas, identifying carbon emission fault nodes and finding system faults, including virtualization functions of hardware resources such as smart meters and carbon emission sensors. The energy routing chip is used for energy scheduling and transmission, planning the best energy distribution route for complex energy transmission networks, supporting the real-time monitoring of energy use by the network and facilitating the on-demand distribution of energy, including the virtualization function of hardware resources such as transformers and distribution boxes; Energy sensing chip is used for the collection and storage status acquisition of renewable energy, providing data support for energy routing function, making it have a global perspective of energy distribution, including the virtualization

function of hardware resources such as various sensors and advanced metering infrastructure equipment.

The network slice management arranger is responsible for managing virtual network functions [32], on the one hand, adding, deleting or redistributing virtual network functions in slices according to business requirements, on the other hand, it can monitor the state of virtual network functions, optimize the performance of network slices, and provide diversified network services for vertical users in low-carbon networks. In addition, edge computing can also enhance the slicing ability of low-carbon network architecture. Edge computing nodes can be used by MANO to manage and optimize slices, specify NFV scheduling strategies, or directly use them in slices to provide computing power for services. Compared with centralized computing, edge computing is closer to network infrastructure and user terminals, which can reduce the delay caused by transmission and facilitate the application of delay-sensitive services, such as carbon emission measurement and energy perception.

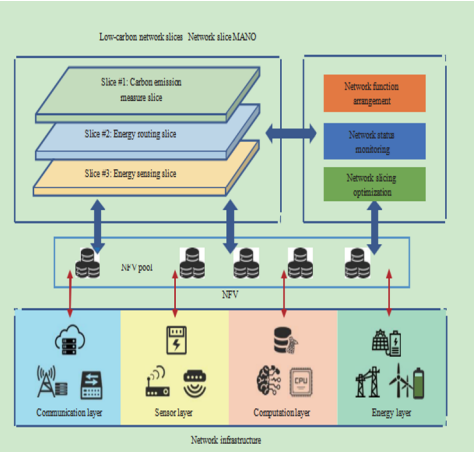

Fig.6 (Network Color Map) Low-carbon network slicing architecture
Figure 6 (Color online) Low-carbon network slicing architecture

3.2.2 computing resource

The next generation mobile communication network supports all kinds of high-rate, high-capacity and ultra-intensive services. In order to alleviate the energy consumption on the network side, a large number of iterative calculation methods have been proposed by the academic circles to improve the system energy efficiency and reduce the energy consumption of the base station. At present, artificial intelligence technology has been adopted to simplify the mathematical iterative solution process [33,34], including traditional heuristic algorithms and popular machine learning (machine learning, ML) method to reduce algorithm complexity and system overhead. In the management and control of computing resources, the research on energy saving and emission reduction mainly focuses on computing task unloading and computing resource allocation [35].

The concrete manifestation of reducing system energy consumption by using computing resource management and control technology is that deep reinforcement learning, DRL) is applied to mobile edge computing, MEC), and computing tasks are offloaded to MEC servers. Usually, data offloading has high power consumption in communication. In order to control the computing resources and improve the energy efficiency of the system, a new hybrid unloading model is proposed in reference [36], which uses the complementary operation of active RF communication and low-power backscattering communication to balance the energy consumption in local computing and data unloading, thus improving the energy efficiency of the system; Different from the traditional machine learning algorithm, which learns from scratch and needs a lot of complicated training data, the transfer learning algorithm can slightly adjust the existing data system or train only part of the data system, thus reducing the calculation consumption and the required training data. Literature [37] reduces the calculation resource expenditure, and further improves the energy-saving effect through transfer learning, which can reduce the required training data and computing resources and speed up the learning process, thus expanding and accelerating the application; Federated learning, FL) can act effectively according to the current state, using idle edge computing resources to obtain results, and the edge server can keep training data locally, thus reducing the consumption of the central controller. Literature [38] uses distributed joint learning algorithm to make the edge device handle the initial calculation, which requires less computing resources. The heavy computing tasks are offloaded to the distributed edge server, which reduces the overhead of computing resources (in this case, the computing power between edge devices and servers) and minimizes the system energy consumption.

The above research manages resources by exploring the coupling relationship between various AI algorithm models and computing resources, energy resources and communication resources.so as to reduce the calculation overhead, improve the system energy efficiency and realize green communication.

3.2.3 Storage resources

In order to overcome the phenomenon of data transmission congestion, slow data processing and delay during business peak hours, and improve the user experience, caching technology can be adopted at the network node for some content that is highly concerned by users. In the cache, frequently requested data items are stored in the network node between the main content server and the user equipment [39,40]. These data are cached before the content request arrives. It is also used to provide services for users during peak hours. Simply put, the cache mainly replaces the extra bandwidth demand through the data storage unit [41]. This not only avoids repeated transmission, reduces the delay of user perception, but also improves the spectrum efficiency and network throughput of the system [42]. However, the process of using the cache unit needs to consume extra energy. Therefore, Green cache technology which can reduce energy consumption while ensuring user experience has attracted wide attention. Literature [43,44] intelligently selects content transmission paths and activates cache nodes according to network traffic demand. Literature [45] proposes an effective utilization mechanism of renewable energy based on content cache and advance push. The specific idea is: when the energy is sufficient, actively cache the content repeatedly requested by users at the base station, Or push the cached data to the user in advance, so that even when the energy of the base station is insufficient and the renewable energy supply is insufficient, the user can still obtain the content quickly and smoothly, and improve the user experience. This idea enables the energy to be used "in advance" to adapt to the uneven distribution of services in time [46], which not only reduces the dependence on grid energy, but also reduces carbon emissions and realizes green communication.

4 Low-carbon-oriented Convergence Architecture and Management Technology of Communication Network and Energy Network

Section 3 discusses how to reduce carbon emissions by reducing communication energy consumption from the perspective of network side. From the perspective of energy supply side, this section will study how to provide energy for mobile communication networks on demand through energy collection, storage and scheduling, and how to realize two-way matching of communication resources, energy resources and business distribution under the framework of communication network and energy network integration.

4.1 Convergence architecture of communication network and energy network

After entering the 5G era, with the increasing demand for communication quality, the large-scale deployment of cellular networks has brought huge energy consumption. Wireless communication systems generate about 2 billion tons of carbon emissions every year [47], 70% of which come from base stations [48]. In order to solve the problem of increasing carbon emissions, The rational use of green energy (such as solar energy, wind energy, tidal energy, geothermal energy, etc.) has attracted worldwide attention. As an environment-friendly energy source, green energy produces zero carbon emission, which injects new vitality into the traditional power supply system. However, due to the fluctuation and randomness of the collection of green energy, there are difficulties and challenges in how to make efficient use of green energy.

Due to the introduction of green energy, the energy network has also become complicated and diversified. In the following research on green energy, although the matching between communication resources, energy resources and business distribution has not been considered, it has made a fundamental and groundbreaking contribution to the resource management and control technology of the energy network. Literature [49] has studied a cellular access network that relies entirely on renewable energy. Based on the energy consumption model and typical flow curve of the base station, the energy consumption demand of the base station is calculated, and the size of the solar photovoltaic panel is determined according to the solar radiation power and the daily energy demand of the base station for some designated positions, and the simulation of the zero-power cellular network is completed. Compared with the reference [49], the reference [50] further adopts the battery energy storage technology to prevent the collected solar energy from being wasted. By analyzing the technical parameters of solar photovoltaic panels and energy storage batteries in detail, the energy autonomy and long-term energy balance of LTE Hong Jizhan are ensured. Literature [49, 50] only relies on statistical load information, and does not optimize energy utilization, which may lead to over-allocation. In addition, it does not consider the constraints such as base station interconnection, communication resource allocation, and quality of service, QoS) requirements, but it still proves that the energy network with green energy can reduce carbon emissions.

This paper studies the multi-base station mobile communication system powered by the combination of traditional power grid and green energy, and puts forward a non-cooperative game model, which is

used to explore the energy distribution strategy of renewable energy suppliers and base stations and reduce the carbon emission of the communication system. Literature [49,51] uses green energy or green energy

Table 4 Research on communication network and energy network integrated architecture

essay	framework	Features/research
[53]	RE-CRAN framework	Separate resources into control plane, data plane and energy plane.
[54]	Multilayer cooperation framework	Multi-layer deployment, each layer is composed of nodes with similar power transmissionlevel and coverage requirements.
[55]	Flexible resource utilization framework	It consists of active and passive components, the former predicts demand and the latter schedules resources according to demand.
[56]	Hierarchical distributed resource management framework consists of three strategies: radio resource allocation, interference coordination and energy sharing.	
[57]	-On the premise that communication resources are related to energy, study appropriate RB allocation and power allocation strategies to reduce energy consumption. [5860]-Coordinate communication resources with green energy supply, optimize communication resource allocation to reduce brown energy use. [61, 62]-Choose communication mode or user-related strategy based on energy distribution to reduce energy consumption.	

It can be combined with the traditional power grid to supply power to the network entities, which significantly reduces the network energy consumption and carbon emissions, which shows that green energy plays a vital role in the energy grid. Literature [52] uses the on/off algorithm based on reinforcement learning to enable base stations to learn energy collection and energy demand patterns independently. In this study, the research on reducing network carbon emissions is only conducted at the energy level, and the distribution of communication resources and services is not considered comprehensively. Therefore, it is necessary to put forward the concept of joint arrangement and scheduling of energy resources and communication resources.

With the introduction of green energy, predecessors have done some research on the integration of communication network and energy network, and put forward some related integration frameworks, as shown in Table 4 [5362]. Literature [53] incorporated renewable energy into C-RAN, and proposed a RE-CRAN structure driven by renewable energy. This structure abstracted and concentrated communication, calculation and energy resources. It is integrated into control plane, data plane and energy plane, which realizes the joint management and optimization of communication resources and energy resources, in which the data plane completes the management of data routing, identifies the random characteristics of QoS requirements related to network traffic, The energy plane (composed of distributed renewable energy resource DER, distributed energy storage device DESD and energy router) completes the collection, storage and flow of green energy and the use of traditional power grid, and the control plane manages network resources and energy resources globally. Literature [54] proposes a multi-layer cooperative green heterogeneous network framework, each layer is composed of nodes with similar transmission power levels and similar coverage requirements. It supports centralized baseband processing, cooperative radio and energy saving in heterogeneous networks. The framework realizes the joint management and control of energy resources and communication resources, aiming at balancing and optimizing spectrum efficiency, energy efficiency and user service quality in heterogeneous wireless networks. However, due to the multi-layer deployment of the design framework, the transmission power of nodes in different layers is different and superimposed with each other, resulting in new complex interference scenarios. More complex interference suppression technology is needed. Literature [55] takes SDN technology as the core, and puts forward an elastic resource utilization framework, the core of which is to schedule energy resources and reduce the consumption of green energy by predicting user traffic. The framework includes two key components, active and passive. The former predicts the fluctuation of each user's capacity demand and makes a plan for a virtual base station, VBS) in a certain (limited) time range in advance; The latter monitors the utilization of virtual machine, VM), and triggers an over-allocation or under-allocation alarm when there is a mismatch between the expected resource utilization and the actual observation. The scale, RRH density and transmission power of VBS can be dynamically changed. In order to dynamically and effectively adapt to the fluctuation of each user's capacity demand, reference [56] proposed a hierarchical distributed resource management framework based on reinforcement learning, which realized radio resource allocation strategy, interference coordination strategy and energy sharing strategy through the combination of three strategies, all of which were constantly updated through reinforcement learning algorithm. To jointly decide the allocation of communication resources and the use or sharing of energy to other base stations. Literature [53,56] puts forward several different communication-energy integration arrangement

structures, and optimizes the resource matching according to their respective structures, which lays the foundation for the subsequent resource management and control technology under the framework of communication network and energy network integration and the matching between communication resources, energy resources and service distribution.

Under the background of the concept of integration of communication network and energy network, some researches on reducing network energy consumption and optimizing the joint use of communication resources and energy resources have been carried out one after another. This paper studies the optimal RB allocation and the corresponding power allocation strategy to minimize energy consumption in H-Crane. Literature [58] proposes a distributed power allocation algorithm for base stations driven by different types of renewable energy, which uses dual decomposition method to decompose the main problem into sub-problems, and the optimal power can be obtained through iterative coordination between communication systems and different types of green energy supplies.

The document [59] studies how to combine energy distribution, sharing and communication resource allocation to minimize the use of brown energy and reduce carbon emissions. The joint optimization problem of RRH-BBU correlation and non-green energy minimization is defined as a mixed integer linear programming problem. Literature [60] jointly optimizes communication resources such as routing, rate control and power allocation to minimize network energy consumption under the constraint of network throughput. In order to search for the optimal route, the weighted Dijkstra shortest path algorithm is used. In order to match the energy resources and communication resources, the weights in the algorithm are defined as the functions of node power consumption and residual energy, which achieves good results. Literature [61] considers communication mode selection (cellular mode or D2D mode) and resource allocation jointly under the background of heterogeneous network enabled by device to device, D2D). At the same time, the QoS requirements of cellular users and D2D users are guaranteed, and a markov decision processes problem is formulated to maximize the energy efficiency of all users through reinforcement learning. In the wireless access network system, considering the joint scheduling of energy resources and communication resources, It is a key issue of energy saving and emission reduction to reasonably select the RRH for each user. Literature [62] proposes three user association strategies based on the nearest user association, single candidate RRH user association and multi-candidate RRH user association considering the energy distribution.

This section has mentioned the matching among communication resources, energy resources and business distribution many times, and the matching among them is the joint scheduling of resources based on the framework of the integration of communication network and energy network. The following paper will conduct detailed research on the matching of energy resources and business distribution and the matching of communication resources and business distribution respectively on the premise of joint scheduling of communication resources and energy resources.

4.1.1 Matching of energy resources and business distribution

The service distribution is manifested in the difference of mobile communication traffic in form. The mobile communication traffic is dynamic in time and distributed in space. The characteristics of traffic depend on users' habits, geographical location, time distribution, network topology and application program types, which leads to the energy demand of base stations fluctuating with time. Similarly, the energy distribution has similar characteristics to the service distribution. As a distributed renewable energy, green energy is highly dependent on geographical location, weather conditions, time and other factors, so

According to the observation of the actual measurement data, there have been many studies [63,64] to analyze the statistical characteristics of business flow and energy distribution, which proves that they are predictable. In common green energy sources such as solar energy and wind energy, the randomness of solar power generation is smaller than that of wind energy, and its predicted value is closer to the real value. Therefore, it is meaningful to predict the solar power generation. In this paper, SAM (solar advisor model) software is used to design the solar power generation model at the location of Yuanwanggu Gymnasium in xidian university by importing the meteorological files at the latitude and longitude and configuring the parameters of solar photovoltaic panels, and the monthly average solar power generation in December 2023 is predicted.

As shown in Figure 7.

In the following studies, as shown in Table 5 [6571], by matching the distribution of energy resources and services, energy waste and unnecessary energy consumption are reduced, and the stability of the network system is guaranteed.

References [72] and [73] respectively developed a distributed optimal user association strategy and a dynamic user association method based on service

awareness, both of which achieved load balance by adjusting the service load. Although they did not match the energy distribution, they provided important ideas for the matching and optimization of the energy distribution and the service distribution. Reference [65] put forward two guiding opinions. On the one hand, the base station should determine how much energy is used at the current stage and how much energy is reserved for the future, and make the best use of the green energy distributed in each time period; on the other hand, guide the traffic load to the base station with larger green energy capacity, and make the best use of the green energy by matching the service distribution, so as to reduce the carbon dioxide emission. Reference [66] introduces a control algorithm and proposes to reduce the energy consumption of the base station in some stages. Reserve energy for the future to ensure that network nodes will not be interrupted even under high-level business load. Literature [67] focuses on the adaptive power management of base stations under various uncertain conditions, divides the business load of base stations into five scenarios: light load, moderate load, heavy load, heavy load in the morning and heavy load at night, and proposes a multi-cycle random planning power management model. It can reduce energy consumption under the condition of uncertain base station traffic load. Literature [68] uses the bidirectional energy flow of smart grid to reshape the uneven energy supply and demand caused by energy distribution characteristics of cellular network, optimize the uneven characteristics of energy distribution, and reliably change in time and space in cellular network.

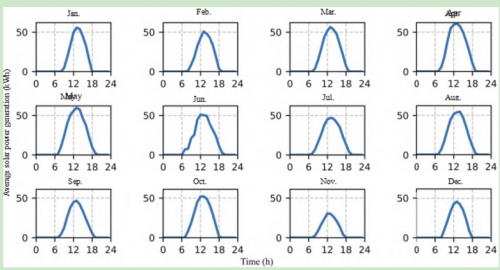

Fig. 7 (color map of online version) Monthly average predicted solar power generation of Yuanwangu Gymnasium of Xidian in 2023.
Figure 7 (Color online) Monthly average predicted solar power generation for 2023 at Invengo Gymnasium of Xidian University

Wireless traffic supply reduces energy consumption and energy cost at the same time. Literature [69] considers that the energy obtained by base stations does not match its business load due to the fluctuating nature of renewable energy, allowing the energy obtained to be transmitted between base stations, and proposes a dynamic energy-aware power allocation algorithm based on Lyapunov optimization. It can improve energy efficiency and realize it by energy cooperation without any channel information, traffic and network resource information. This embodies the idea of matching energy distribution with business distribution, but it lacks the optimization of communication resources. Because the prior information of energy arrival process and channel is not available, Literature [70] proposes an energy cooperation and power allocation strategy based on deep deterministic policy gradient (DDPG) to solve the energy cooperation problem in distributed storage networks. Literature [70] considers the management of radio and energy resources, but only considers power control. User scheduling, user QoS requirements and inter-cell interference are not considered. Literature [71] puts forward an energy-agile packet scheduling algorithm to shape elastic mobile traffic to match energy distribution, which is embodied in optimizing packet scheduling to balance the energy consumption of base stations in various time periods. The transmission of some packets will be delayed by h slots, and h is obtained by matching service distribution with energy. In exchange for the energy saving of the main power grid through time delay, literature [74] studies the resource allocation problem of minimizing the energy consumption of the power grid under the condition of meeting the user's QoS. Literature [74] deduces the average outage probability under different energy levels by means of dynamic programming, and weighs the user's QoS requirements according to this probability to get the optimal resource allocation strategy. Thus, the energy-aware communication resource scheduling is realized, and the energy distribution and service distribution are matched by dynamically adjusting the allocation of communication resources, thus improving energy efficiency and ensuring user satisfaction. It is worth noting that the document [60] proposes that it is impossible to transmit energy between network entities without any loss, and the loss may account for 7% of the transmitted energy, and in extreme cases it may even reach 55%. Energy storage batteries also have a high cost, and storing green energy in batteries will also cause losses, with 0.1% of electricity consumption per hour. There are three ways to use the collected green energy, including immediate use of energy, energy storage and energy transfer. Therefore, how to make full use of green energy has become a key issue for matching energy distribution with business distribution.

4.1.2 Matching between communication resources and service distribution

As the key to sustainable development, the importance of green energy lies in the efficient utilization of

resources and the minimization of environmental impact.

Table 5 Research on the matching between energy resource and traffic distribution

Main contents of literature
[65] Guide high-traffic services to base stations with large green energy capacity to maximize the use of green energy and reduce carbon emissions.
[66] The base station consciously stores energy for the future to prevent the interruption of network service under high-level business load and ensure the stability of the network system.
[67] According to the load, the service distribution is divided into five scenarios, and the energy management of multi-period random planning is carried out according to different service scenarios. [6870] By using the two-way information flow of smart grid, the non-uniform characteristics of energy distribution are optimized, so that the energy obtained by base stations can match the service load.
[71] Actively delay the sending of some data packets to shape the energy distribution of elastic mobile traffic matching.

Table 6 Related research on the matching between communication resources and service distribution

Table 6 Research on the matching between communication resource and traffic distribution

Main contents of literature
[75] Based on deep reinforcement learning, data unloading and bandwidth allocation are carried out according to business perception, reducing energy consumption and bandwidth cost.
[64] According to the prediction of business traffic information, the communication resource allocation combining short time scale with long time scale is proposed, thus reducing energy consumption. [76, 77] According to business requirements, user association and resource allocation are carried out as needed to reduce energy consumption.
[78, 79] Using machine learning method, the communication resources are jointly optimized according to the predicted business information.
[80] Adding some robustness to the uncertainty of prediction, a robust resource allocation method based on mobile resource awareness is proposed.

Similarly, the effective prediction of traffic distribution can significantly improve the efficiency of communication resource allocation and reduce resource waste, thus supporting the sustainable development of communication networks. In recent years, the allocation of communication resources under the dynamic fluctuation of traffic distribution has become a research hotspot. Therefore, some studies have begun to explore the matching between communication resources and traffic distribution from the perspective of prediction, and the specific research situation is shown in Table 6 [64,7580]. These studies are for further understanding and improvement.

Literature [75] considers that the wireless channel conditions will change with time and environment, and proposes a joint optimization method of data unloading, bandwidth allocation and service awareness of Internet of Things devices based on deep reinforcement learning, which matches communication resources and service distribution and reduces energy consumption cost and bandwidth cost. However, renewable energy is not regarded as a manageable resource, and energy sharing is not considered. According to the characteristics of service distribution, literature [64] puts forward a management mode combining long-time scale (minutes or hours) with short-time scale (milliseconds). In the short-time scale, BS nodes driven by renewable energy are preferentially selected to provide instantaneous supply for users' needs, and the behavior of renewable energy is predicted in the long-time scale. The literature [76] mentioned that the energy consumption of network deployment and communication resource allocation should be determined by the service distribution and adaptive, that is, the realization of supply and demand matching, and established a stochastic optimization problem. By dynamically adjusting the operation mode of the base station, realizing the best association of users, optimizing the distribution of subcarriers and power, The energy consumption of the whole system is reduced. Literature [77] considers the change of service distribution characteristics and users' QoS requirements, and solves the problem of minimizing the average energy consumption of the power grid through two-order dynamic programming algorithm. In the first stage, the switching state of the base station is optimized, and in the second stage, the RB allocation and renewable energy allocation are adjusted. This communication resource allocation strategy can effectively reduce energy consumption and improve the capacity and coverage of the network. However, it is still not well adapted to the time-varying traffic distribution and can only achieve optimal performance under the condition of uniform traffic distribution.

In view of the statistical characteristics and predictability of service distribution and energy distribution, they can be regarded as non-causal knowledge, and the joint arrangement and optimization of them and communication resources may be a non-deterministic polynomial problem, which is not easy to be solved directly by mathematics. Some schemes based on machine learning are proposed to match and optimize resources. Literature [78] is developed by using enhanced online learning, and the available RBs are classified according to the user's traffic priority and location prediction, and a communication and energy resource allocation under H-Crane is proposed. However, what is not considered is the prediction and rational use of energy resources. A neural network model is designed in reference [79], which can predict the energy consumption of different resource allocation schemes by learning historical communication data and environmental information. Then, based on these prediction results, the model can intelligently select and allocate communication resources. In order to improve energy efficiency to the greatest extent. Most excellent results depend on perfect traffic distribution and energy distribution prediction, which is obviously unrealistic. Literature [80] considers how to increase some robustness to the uncertainty of prediction, and puts forward a robust active resource allocation method for mobile resource awareness. By using probability constraint ,Modeling QoS requirements in the sense of probability is robust to the

uncertainty of prediction. Hidden Markov model is used to predict the user trajectory and pre-allocate resources for mobile users in time and frequency domain.

Therefore, in view of the dynamics and randomness of mobile communication traffic and green energy, it is very important to understand the characteristics of green energy power generation and the dynamics of mobile network energy consumption for designing and optimizing green energy-driven mobile networks. It cannot be ignored that while improving energy efficiency and reducing carbon emissions, it is still necessary to consider the reasonable allocation of communication resources and the QoS requirements of users. Therefore, how to integrate energy networks with communication networks, Matching communication resources, business distribution and energy distribution to realize the integrated arrangement of energy resources and communication resources is a key issue in achieving the goal of "double carbon".

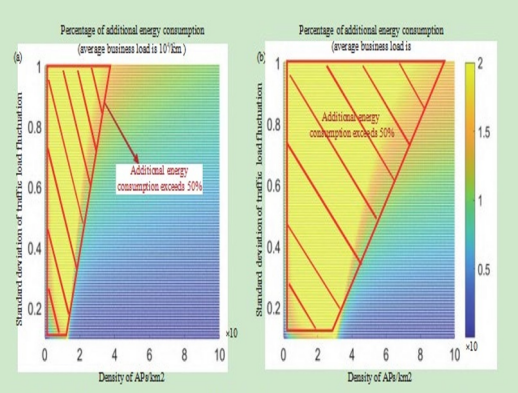

Fig. 8 (Network Color Map) Relationship between High Energy Consumption Area and Service Jitter Range (Standard Deviation)
Figure 8 (Color online) Relationship between high-energy consumption areas and traffic jitter range (standard deviation)

4.2 Native green grid Architecture of Communication-Perception-Energy Fusion

The above work only studies the one-way matching of energy distribution and business distribution or the one-way matching of communication resources and business distribution under the convergence framework of communication network and energy network, but lacks the research on the mutual matching of energy resources, business distribution and communication resources. Among them, the difficulty of matching energy resources and business distribution lies in the unpredictability of distributed renewable energy collection and supply in multi-energy power generation grid, which will lead to complex energy resource scheduling and supervision [81]; The difficulty of matching communication resources with energy distribution is that the space-time randomness of service distribution will lead to uneven load of communication network and intermittent power load, which makes it difficult to deliver energy resources accurately. Figure 8 reveals the percentage of network additional energy consumption corresponding to different standard deviations of service load fluctuation and access point density under the condition of random arrival of services. Among them, the standard deviation of load fluctuation depicts the second moment of service arrival to describe the randomness and suddenness of services.

Among them, qc is used to describe the probability that users request data services. Considering the jitter of service requests, it is a non-fixed value here, and its probability density function is fqc (x). It can be seen from Figure 8 that when the access point density is constant, the more frequent the service load jitter, the more additional energy consumption the network generates. When the standard deviation of service load jitter is fixed, the greater the density of access points, the less the ability to cause the network to generate additional energy consumption. Therefore, network densification is an effective means to overcome the problem of high energy consumption caused by service load jitter. At the same time, the area where the percentage of additional energy consumption exceeds 50% in the figure is a feasible area to reduce network energy consumption by 50%. By optimizing network performance and eliminating the randomness of services in this interval, it can be achieved.

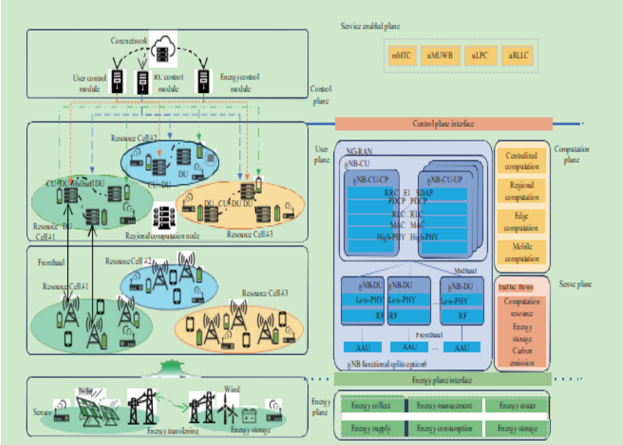

Fig. 9 (network color map) Native green grid architecture for communication, perception and energy fusion.
Figure 9 (Color online) Green-native network architecture: integration of communications, sensing, and energy

Significantly reduce network energy consumption.

Under the guidance of the above feasible region of network energy consumption optimization, this paper proposes a native green grid architecture of communication, perception and energy fusion from the perspective of eliminating the randomness and unpredictability of energy distribution and service distribution, as shown in Figure 9. Compared with the traditional architecture of energy network and

communication network fusion, this architecture expands the perception layer. The purpose is to make the communication network have the function of energy perception and service perception. The service perception function enables the communication network to know the evolution of the behavior and needs of end users in time and space, which is convenient for the network to make traffic prediction in complex scenarios and optimize the allocation of communication resources according to network behavior. The energy sensing function enables the communication network to obtain the collection state, storage state and consumption state of energy in real time, and feed back the energy network with the service distribution obtained by the service sensing function, so as to generate the optimal energy flow matching with the power load. The expansion of the sensing layer enables the communication network to predict the service distribution, eliminate the randomness of energy distribution, and make it possible to match the energy resources, service distribution and communication resources.

Optimizing energy flow by forecasting business is a passive matching of energy network under the condition of known business distribution. Native green grid architecture also supports active matching of the same energy distribution by shaping business under the condition of known energy distribution. The starting point of active matching is that renewable energy is not as stable and reliable as traditional energy, and its distribution is affected by external environment such as weather, climate, illumination, air pressure and season. Therefore, it is more difficult to predict the energy distribution than to predict the service distribution. Therefore, it is a more practical energy-saving means to adapt the service distribution to the energy distribution. The basic principle of service shaping is that the network dynamically adjusts the service period of the service according to the change of the energy distribution, so that the fluctuating service can be completed in batches and stably on a certain time scale. Specifically, it can be described as: in the low valley of energy arrival, the service is delayed, At the peak of energy arrival, the services will be concentrated and the services that may be needed in the future will be cached in advance. Service shaping eliminates the randomness of service distribution and can further enhance the matching degree between energy resources, service distribution and communication resources.

Based on the native green grid architecture, the carbon emissions of three cases, namely, the matching of energy resources and business distribution, the matching of communication resources and business distribution and the bidirectional matching among them, are simulated. The simulation scenario is a 100 m 100 m two-dimensional plane, and three base stations BS1, BS2 and BS3 are deployed, with five assignable carriers for each base station. The maximum transmission power is 2 W. In order to reflect the non-uniform distribution of services, there are 5 users in the coverage area of BS1, 3 users in the coverage area of BS2 and 2 users in the coverage area of BS3, respectively, corresponding to heavy, medium and light loads. The QoS requirements of each user are set at 5 Mbps.

Each user can only be served by one base station and can only occupy one carrier. The power optimization is simulated for 500 times (randomly generating channels each time), and the network performance under one-way matching method and two-way matching method is counted and compared.

The simulation results are shown in Figure 10. The results show that although the power consumption of the whole network can be reduced by more than 58% under the condition that the average downlink rate of the whole network is unchanged by means of resource allocation and power control, the reduction of network-side power consumption by 50% does not mean that the carbon emission of the system can be reduced by 50%, and its carbon emission is still at a high level. The reason is that the system carbon emission is not only determined by network-side energy consumption. It also depends on the green energy collected by the energy grid side and the electric energy transmitted by the traditional power grid. The randomness and instability of the distribution of green energy in space and time can be reduced by the two-way matching method, and the sudden arrival of business in space and time can be eliminated, so that the energy consumption of the network side can be reduced and the carbon emissions of the system can be reduced to some extent. It is proved that the native green grid architecture can simultaneously reduce the energy consumption and carbon emissions of the system.

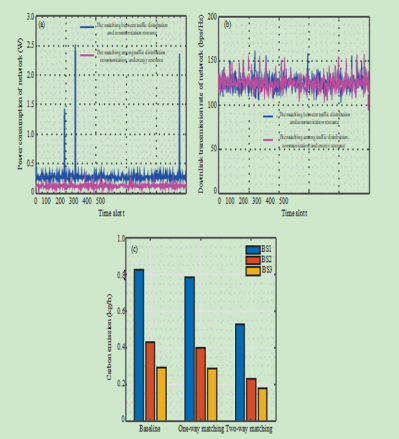

Figure 10 (Network Color Map) Performance Simulation of Communication System under One-way/Two-way Resource Matching

Figure 10 (Color online) Performance of network with one-sided or dual-sided resource matching. (a) Power consumption of network versus time slots; (b) downlink transmission rate of network versus time slots; (c) algorithm comparison

5 Difficulties and challenges in the future

New materials and new devices [82]. Facing the next generation of mobile communication networks, terahertz communication has become a potential technology. The existing research shows that compared with 5G systems, terahertz communication systems have higher frequency bands, and their key devices (such as RF amplifiers) have higher power consumption and lower energy efficiency. Widespread deployment and application will inevitably lead to extremely high energy consumption and carbon emissions. Therefore, in order to achieve green communication, it is necessary to save energy from hardware, such as low energy consumption.

Potential problems in the sleep mechanism [83]. Different levels of sleep are the most direct and effective means to save energy and reduce carbon emissions in the network, but under the sleep mechanism, the base station will conduct frequent switching/activation behaviors, which will have an impact on the service life of the base station. Therefore, on the one hand, it is necessary to adjust the sleep period according to the network load and predicted user activities, so as to optimize the sleep strategy of the base station and reduce frequent start and stop, on the other hand, it is necessary to shape the services in the network to maintain the start and stop of the base station.

Challenges under the dual-network integration. (1) The integration of communication network and energy network will bring challenges of technical standardization and compatibility, including the expansion and maintenance of hardware and software, and the unified management and control of various devices and sensors; (2) unified communication and energy data will involve a lot of sensitive information, such as users' energy and data traffic usage. Therefore, data privacy protection and network security protection are of great significance. How to protect the private information generated by communication networks and energy networks is still facing difficulties and challenges.

6 summary

Aiming at the goal of "double carbon", this paper investigates the existing green communication technologies with the aim of improving the energy efficiency of the mobile communication network and reducing the carbon emissions of the system. On the one hand, it investigates the low-energy networking technology, transmission technology and resource management and control technology from the perspective of matching the network resources with the service distribution, and the results show that a single method of reducing the energy consumption of the network side cannot fully reduce the carbon emissions. On the other hand, from the perspective of matching the distribution of energy resources and services, the low-carbon technology under the framework of communication network and energy network integration is investigated. The results show that the difficulty of matching the distribution of energy resources and services lies in the fact that the space-time randomness of traffic distribution will lead to uneven load of communication network and intermittent power load, which makes it difficult to deliver energy resources accurately. In this paper, a native green grid architecture integrating communication, perception and energy is proposed. By predicting the traffic distribution and eliminating the randomness of energy distribution, this architecture can not only ensure the network service capacity, but also reduce the carbon emission and energy consumption of the system, which provides a feasible idea for building a future zero-carbon emission network.

Declarations

Ethical Approval: It applies to human studies. Ethical committees---Education Ethics Branch of the Chinese Ethics Society approve to contribute my paper. I consent to participate and consent to publish my paper.

Competing interests： My interests of a financial or personal nature have no conflicts with anyone.

Author contributions: The author approved the concept and design,data collection and analysis of the final article The authors claim that none of the material in the paper has been published or is under consideration for publication elsewhere. I don't have project grants.

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