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CHINA TELECOM

China Telecom 5G Technology White Paper

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Content

1 Introduction

The 13th Five-Year Plan outline of China puts forward requirement clearly about "actively promoting the fifth-generation mobile communication (5G) and ultra-wideband key technologies, launching 5G commercial use". To implement such proposals, Ministry of Industry and Information Technology (MIIT) re-emphasized in its blueprint "Development Planning for Information and Communication Industry (2016-2020)" released in January 2017 to support 5G standard research, technical trial and commercial service, becoming one of the global leaders of 5G standard and technology in the 13th Five-Year period.

5G is a basic platform for leading technological innovation, realizing industrial upgrading and developing the new economy. As an operator of national information infrastructure, China Telecom undertakes the important mission to implement network power and 5G national strategy. China Telecom also adheres to the principle of market driven and technology innovation driven, and focuses on technology, business and operation innovation. It will ultimately facilitate transformation 3.0 strategy and promote implementation of CTNet2025 network transformation, fulfilling the long-term development of the enterprise.

China Telecom proposes evolution strategy and milestones, and explores new construction scheme and operation model of 5G network based on service requirements, future network architecture and main challenges in 5G development. China Telecom will actively promote 5G business innovation combining with vertical industry and build a robust 5G ecosystem. Driven by 5G innovation, China Telecom will further push forward the development of "smart network, ecological business, intelligent operation".

2 Requirements and Challenges

2.1 Requirements of service development

The vision of 5G is to deal with the explosive growth of mobile data traffic, massive device connections, emerging business and application scenarios in the future. 5G will deeply integrate with vertical industry to achieve “Internet of everything” and establish the foundation of digital transformation of society and economy.

ITU has defined three usage scenarios for 5G, including eMBB (enhanced Mobile Broadband), mMTC (massive Machine Type Communication), and URLLC (Ultra Reliable & Low Latency Communication). In fact, different scenarios always have differentiated requirements on multiple key indicators, thus 5G needs to support the customized combination of reliability, delay, throughput, positioning, billing, security and availability. 5G should also manage the higher security risks associated with “Internet of everything” by providing differentiated security services for diversified usage scenarios and protect user privacy.

Typical applications of eMBB include ultra-high-definition video (UHDV), VR and AR. These scenarios require key performance indicators including 100Mbps user experienced data rate, dozens of Gbps peak data rate, dozens of Tbps data traffic density per square kilometer, over 500km/h mobility, etc. Additionally, some interactive applications are also time-sensitive, for example, the immersive experience of VR demands 10 milliseconds level delay.

Typical applications of URLLC include auto-control, drone control and automatic drive, etc. These scenarios are latency sensitive and require ultra-high reliability. The latency requirements of automatic drive and industrial manufacture are millisecond level and 10 milliseconds level respectively, with 5G network availability close to 100%.

Typical applications of mMTC include smart city, smart home, etc. These applications in all walks of life require high and diversified connection density. For metering application in smart city, the terminals must be low cost and low power consumption, and the network should support massive small data packets. Video surveillance not only has high deployment density, but also requires the terminal and network to support high data rate. Smart home services are relatively insensitive to delay, but the terminals need to adapt to drastic environmental changes.

2.2 Main Challenges

2.2.1 Challenges of radio chipset

Radio devices mainly include analog chipset such as baseband digital signal processing unit, ADC/DAC, frequency converter, RF front-end, etc.

5G achieves higher throughput and lower user plane delay by adopting shorter scheduling interval and faster HARQ feedback, which requires higher baseband processing capability of 5G system and terminal, and consequently leads to more challenges on the baseband chip technique.

5G supports higher frequency band, larger carrier bandwidth and more channels, which also puts forward higher demands on analog devices, mainly including ADC/DAC, power amplifier and filter. To support larger carrier bandwidth, ADC/DAC requires higher sampling rate (such as 1GHz). To support frequency above 4GHz and higher power efficiency, power amplifier needs to use GaN materials. The number of filters increases correspondingly with the rapid increase of channels in the base station. Consequently, the volume and weight of the filter should be further reduced by adopting effective methods such as ceramic filter or miniaturization of cavity filter, etc.

The main challenge of analog chipset is lack of industry scale. The output power/efficiency, volume, cost and power consumption of the new power amplifier, and performance of the new filter cannot satisfy commercial requirement of 5G. Especially for RF chipset and terminal chipset integrated with RF front-end, although certain development and production capability have been achieved, further improvement is still needed in terms of industry scale, yield rate, stability and cost-performance. As for millimeter wave band in the future, the industry is required to make greater efforts to meet the higher performance requirements of active and passive component.

2.2.2 Challenges of multi-access convergence

Mobile communication system has experienced rapid development from the first generation to the fourth generation. The commercial network gradually forms a complex situation of multiple radio technologies, diverse spectrum utilization and different coverage, while long-term coexistence of multiple access technologies become a prominent characteristic. In 5G era, several types of networks in an operator will co-exist for a long time, including 4G, 5G and WLAN. How to efficiently run and maintain different networks, reduce operation and maintenance cost, realize energy conservation, and improve competitiveness become the problem that every operator need to solve.

Mobile Internet and Internet of things will be the main driving force for mobile communication in 2020 and future. How to collaborate and efficiently manage the multi-access network, while satisfying the technical indicators and application scenarios of 5G, becomes the main technical challenge of 5G multi-network convergence.

- Challenge of network architecture. The multi-network convergence architecture of 5G will consist of multiple radio access networks and core networks, including 5G, 4G, WLAN, etc. How to make efficient architectural design such as the choice of core network and access network anchor, while reducing complexity of network upgrade and influence on existing network should be studied.
- Challenge of traffic offloading. The traffic offloading mechanism in 5G multi-network convergence requires to transmit user plane data flexibly and efficiently in different access networks and minimize the impact on the underlying transmission of each access network. Meanwhile, effective offloading hierarchy selection is required according to scenarios and performance, such as core network, IP or PDCP sublayer.
- Challenge of connection and mobility control. 5G has more complex application scenarios, more access technologies, and higher mobility performance requirements. Compared with 4G, the connection management and control of 5G network need to be simpler, more efficient and more flexible.

2.2.3 Challenges of flexible network architecture

The service-driven 5G network architecture aims to flexibly and efficiently meet diversified mobile service requirements, which pose challenges including network functions, architecture, resources and routing. Based on NFV/SDN and cloud native technology, 5G achieve virtualized and cloudified deployment. However, the container standards are not yet clear and still in the initial stage. The 5G network cloudified deployment must figure out how to meet the requirements of user plane forwarding and provide sufficient isolation. Combining network modularization and control and forwarding separation, service-oriented 5G network can be rapidly deployed according to different service requirements, dynamically scale-in and scale-out, and lifecycle management of network slices, such as end-to-end flexible network slicing, adaptive scheduling of service routes and flexible allocation of network resources, and cross-domain, cross-platform, cross-vendor, and even cross-operator services, all of which pose great challenges to 5G network operation and management.

2.2.4 Challenges of efficient bearer technology

Compared to 4G network, 5G network bandwidth demand is increasing exponentially. 5G scenarios impose high requirements on bearer network bandwidth, latency, flexibility and cost. Reducing the cost of 25G/50G optical modules and WDM transmission at the edge is a big challenge for bearer network. The millisecond-level latency of URLLC service requires the flattening of the network architecture, the introduction of the MEC, and the rational layout of the nodes, which is another challenge for the bearer network. 5G cloud core network, edge computing and network slicing lead to the requirements of connection flexibility for 5G backhaul network. How to optimize routing and control to meet the requirements of forwarding flexibility and easy operation and maintenance of 5G bearer network is the third challenge.

2.2.5 Challenges of terminals

Compared with 4G terminals, 5G terminals become more complex, having diversified types and differentiated techniques. The initial form of 5G terminals is dominated by mobile phones in eMBB, and the planning for the remaining scenarios (such as URLLC and mMTC) will gradually become clear with the maturity of the standard and industry.

The multiband access with large bandwidth and high-performance indicator present new challenges on antenna, RF and other aspects of terminals. Considering user experience, 2T4R is preferred as the basic scheme of the transceiver in sub-6GHz. The antenna design should be optimized to solve issues of terminal space and antenna efficiency issues caused by the increasing number of antennas. Hardware and algorithm of RF front-end chipset should be optimized according to5G new features (such as high frequency, large bandwidth, new waveform, high emission power, low power consumption, etc.), and development of the RF front-end industry chain should be further promoted.

3 5G Target Network Architecture

3.1 “Three Clouds” overall network architecture

The future network will become more flexible, agile, converged and open. “Three Clouds” is an abbreviation for logic architecture of 5G network and includes three logic domains: Access Cloud, Control Cloud and Forwarding Cloud, as shown in Figure 1.

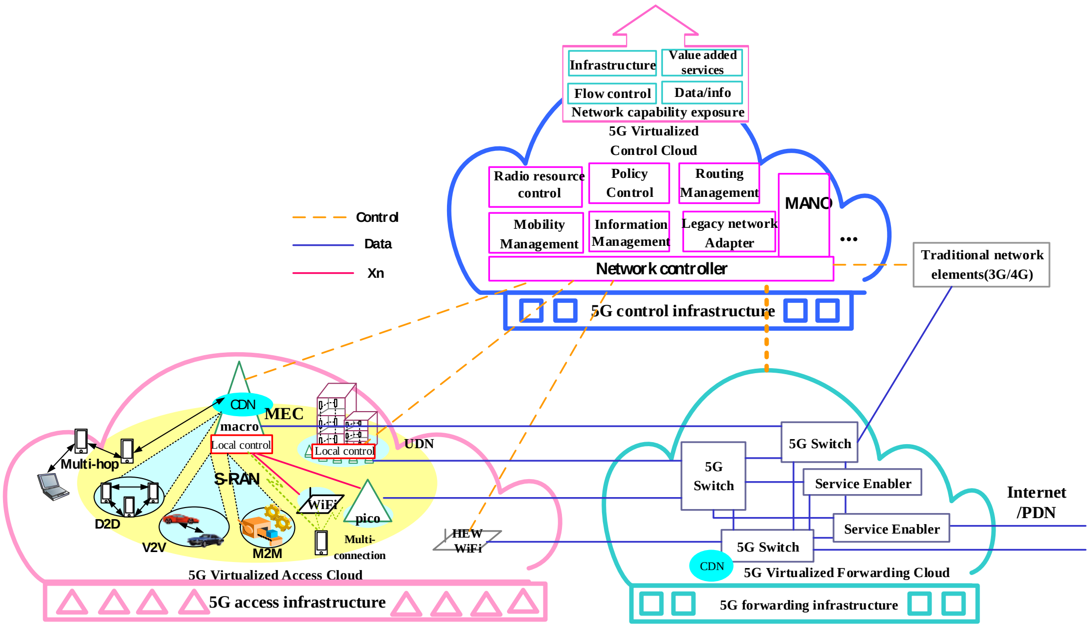


Figure 1 “Three Clouds” Network Logic Architecture

5G network based on “Three Cloud” will be flexible and converged. Control Cloud will have functions such as policy control, session management, mobility management, policy management, information management, service-based capability exposure, and realize customized network and service. Access Cloud will support smart radio access for users and efficiently converge multiple access technologies. Edge computing capability is also provided. Forwarding Cloud will effectively forward and transmit different traffic and ensure end-to-end quality of services based on path management and resource scheduling of Control Cloud. “Three Clouds” 5G network architecture is inseparable and collaborative and can be implemented on the basis of SDN/NFV.

3.2 Control Cloud

Control Cloud achieves control function of 5G network and controls Access Cloud and Forwarding Cloud. Control Cloud consists of several virtual network control function modules, including access control management module, mobility management module, policy management module, user information management module, path management/SDN controller module, security module, slice selection module, capacity exposure module, corresponding network resource orchestration, etc. These function modules are logically similar to the control network elements of the mobile network which complete mobile communication process and control service. But in implementation, these function modules are based on virtualization technology, which optimize the relationship between network functions and achieve network control and bearing separation, network slicing and service-based architecture, etc.

Network capability exposure module is the core for 5G network to open to third party. The modular and slicing techniques, centralized network control and data resources of 5G network benefit network exposure.

5G network resource orchestration module is the core of virtual resource management and control which includes three sub-modules: orchestrator, VNFM and VIM. This module provides a manageable, controllable and operable environment for 5G network under virtualized environment.

3.3 Access Cloud

In future mobile communication system, a variety of wireless access systems will coexist for a long time. In view of diverse service characteristics, it is needed to consider service requirements, network state, user preferences and terminal capability to carry out differentiated data transmission and bearer policy, including flexible scheduling and distribution, traffic offloading, aggregation, etc. Therefore, the balance between system resource utilization and service quality will be guaranteed. Access Cloud of 5G will be a network of multi-topology forms, multilevel types and dynamic, which can provide centralized, distributed or layered deployment. It also provides high data rate, seamless handover and extremely user experience through flexible radio access technology. Deployment of 5G radio network should consider multiple factors such as service application properties, network features and network environment conditions.

The requirements of Access Cloud function include new radio access technology, flexible resource collaboration management, complete across-system convergence, radio network virtualization, edge computing and radio network exposure. Based on centralized access control module, 5G network can build a fast, flexible and high-efficient collaboration mechanism to integrate different radio access technologies and improve the resource utilization of the mobile network.

3.4 Forwarding Cloud

As 5G core network realizes the complete separation of control plane and data plane, Forwarding Cloud only focuses on the high-speed forwarding and processing of the data flow. Forwarding Cloud logically consists of high-speed forwarding unit and service enabling units. In traditional network, service enabling unit is chain-type deployed behind gateway. In Forwarding Cloud of 5G network, service enabling units and forwarding units are deployed in mesh architecture and collectively receive path management and control. Forwarding Cloud will achieve flexible selection between the forwarding unit and service enabling units according to both the centralized control of

Control Cloud and service requirements, with software defining the forwarding path of the traffic.

Additionally, Forwarding Cloud can reduce service delay and improve user experience through caching top contents according to the cache policy of Control Cloud. To improve data processing and forwarding efficiency, Forwarding Cloud will report network state information to Control Cloud for centralized optimization control. In view of the propagation delay between Control Cloud and Forwarding Cloud, Forwarding Cloud needs to locally process some latency-sensitive events.

4 5G Network Evolution Strategy

4.1 5G network is key to CTNet2025 network transformation

Based on key technologies including SDN, NFV, and cloud computing, CTNet2025 strategy aims to build a simple, agile, intensive, and open network architecture. CTNet2025 is a unified architecture of fixed network and mobile network. 5G network as the evolution of mobile network is an important part of the CTNet2025 network transformation, and it is also the best opportunity for realizing CTNet2025 network architecture.

The design of the 5G core network incorporates the ideas of SDN, NFV, and cloud computing, and has the characteristics of separation of control plane and user plane. The control plane adopts a service-based architecture and virtualization implementation. Based on a unified NFVI resource pool, virtual machine or container over virtual machine are used to achieve cloud deployment and flexible scale-in and scale-out. It is also convenient and flexible to provide network slicing. Edge computing can be implemented by moving UPF to the edge and virtualizing applications. UPF can be implemented based on general hardware (x86 servers) or dedicated hardware.

In terms of 5G RAN, DU can hardly be virtualized and CU virtualization is difficult and costly in the short-term. Thus, applying dedicated hardware is more reasonable. In the long term, with the development of NFV technology, CU virtualization can be considered in accordance with the requirements of service and network evolution.

5G network achieves co-arrangement with other networks and capability exposure through a unified coordination and orchestration layer of the entire network.

5G network should make use of the advantages of fixed network resources and leverage fixed mobile convergence to enhance its competitiveness.

- Fixed and mobile network resources sharing is implemented by overall planning of access sites, optical fiber cable network and other infrastructures to reduce the difficulty of 5G deployment. China Telecom will make full use of existing broadband access offices to deploy OLT, 4G BBUs, 5G DU/CU and other access layer equipment, so as to form full-service access offices. China Telecom will utilize the optical fiber cable network resources based on comprehensive consideration of the requirements of fixed broadband and 5G RAN bearer.
- For virtualization of fixed network and mobile network, China Telecom will comprehensively plan and construct NFVI resource pools to enhance the flexibility of virtualized network element deployment and NFVI resource utilization. China Telecom will utilize the advantages of central offices and access offices to introduce NFVI on-demand, and provide computing, storage, and offload functions to support 5G edge computing, virtualized mobile network functions (such as UPF), and potential virtualized fixed network functions.
- China Telecom will construct a unified coordination and orchestration layer for fixed and mobile networks to achieve cross-vendor, cross-domain, cross-network, cross-SDN/NFV, cross new and legacy networks coordination, and to support flexible service provisioning and unified capability exposure of fixed and mobile networks.

4.2 5G evolution strategy and principles

Judging from the laws of the development of mobile communication technologies, the evolution of 5G technologies and industry chains requires a long-term process. It is expected that 4G will coexist with 5G network for a long time. In the future, 5G network will be combined with new capabilities such as cloud computing and IoT to meet the requirements of vertical industries. 5G will create huge business opportunities in the areas of electric power, logistics, banking, automotive, media, healthcare, smart city, etc. In the future, China Telecom can accurately focus on the target markets and effectively increase 5G ROI.

China Telecom's network evolution strategy will comprehensively consider factors such as service requirements, user experience, maturity of technologies, terminal ecosystem, and construction cost.

- Multi-network convergence principle: 4G, WLAN and 5G are expected to coexist for many years, which can meet diversified demands and provide seamless service to users.
- Phase-by-phase migration principle: large-scale and frequent network upgrades should be avoided, and stable network operation should be guaranteed.
- Cost efficiency principle: the cost should be considered when choosing 5G technologies and solutions. In addition, it is necessary to make full use of existing resources for network construction and achieve fixed mobile convergence to form a differentiated competitive advantage.

4.2.1 General strategy of 5G

In the initial stage of 5G network construction, the development of 5G not only needs to fulfil requirements of emerging services and scenarios, but also should fully consider the compatibility with 2G, 3G and 4G networks. China Telecom’s 5G network evolution strategy is divided into two phases: the near-term (for commercial 5G service in 2020) and the mid-to-long-term (for CTNet2025 network transformation). Facing diverse requirements of services, 5G will realize application-aware multi-network collaboration and fixed mobile convergence. China Telecom will promote the application of AI in 5G network management, resource scheduling, energy conservation, and edge computing to provide a smart 5G network.

4.2.2 Wireless network evolution strategy

- SA 5G NR is preferred, considering the network evolution, legacy network, service capabilities, terminal performance and other factors.
- In the early stage of 5G, based on the SA network architecture, CU/DU integration solution is adopted with characteristics of low deployment cost, low latency, low-complexity operation and maintenance, and short construction period.
- According to the actual scenarios and requirements, 64-port 192-oscillator massive MIMO is preferred at traffic hotspots to increase system capacity and coverage.
- In the mid-to-long term, the network will be upgraded on-demand to support URLLC and mMTC, and the CU/DU split architecture will be introduced in due course.

4.2.3 Core network evolution strategy

- 5G network will adopt the SA solution and coordinate 4G and 5G through the core network interworking. In the early phase, eMBB use cases will be primarily focused.
- 5G core network will utilize service-based architecture and cloudified deployment. Control plane is centralized to globally schedule user plane resources. User plane can be moved to the edge on-demand and distributedly deployed. 5G core network should support following features.
  - ✓ End-to-end network slicing to achieve the matching of networks and different service types, and the individual requirements of vertical industry.

    - ✓ Edge computing to support low-latency high-traffic local services. User identification, billing, and auditing issues of edge computing in 4G network need to be solved. China Telecom must be well prepared for innovative edge computing revenue model.

- ■ The 5G core network must have the ability to provide voice service. In the initial stage, it will adopt the solution of 5G fall back to 4G and provide voice service through VoLTE.
- ■ With the evolution and improvement of standards and technologies, the 5G core network will be upgraded to support mMTC and URLLC scenarios. As multi-network convergence technology and industry well developed, 5G core network shall support the unified management and authentication of multiple access, data concurrency or data scheduling among multiple access networks, and service continuity.

4.2.4 Bearer network evolution strategy

- ■ The 5G bearer network should follow the principles of fixed mobile convergence and comprehensive bearer. It should be considered in conjunction with the construction of fixed broadband network. The optical fiber cable network is regarded as the unified physical infrastructure for fixed and mobile network. Resources such as telecom rooms and bearer equipment should be shared as much as possible to achieve rapid deployment at a low cost and form a differentiated competitive advantage for China Telecom.
- ■ The bearer network should meet the requirements of high data rate, low latency, high reliability, flexibility and high-precision synchronization of the 5G network, and support network slicing.
- ■ In the scenario where the optical fiber resources are sufficient or the CU/DU is deployed distributedly, the 5G fronthaul will mainly use point-to-point optical fiber connection, and the BiDi technology should be adopted. In the scenario where the optical fiber resources are not sufficient and CU/DU is

concentratedly deployed, a bearer solution based on WDM may be adopted, which includes passive WDM, active WDM/M-OTN, and WDM PON.

- For 5G backhaul, in the early stage, considering that the traffic is relatively light, relatively mature IPRAN solution is suggested. Later, based on the service development, OTN can be used in heavy traffic areas. PON technology can be used as a supplement in some scenarios.
- Commercialized equipment can be used to meet 5G backhaul requirements in the early stage. SR, EVPN, FlexE/FlexO interface, M-OTN and other new features shall be gradually introduced. Backhaul access layer will introduce higher data rate (such as 25G/50G) interfaces as required. In the mid- and long-term, to meet the need of 5G scale deployment, China Telecom will build a backhaul network with high data rate, ultra-low latency, intelligent controlling based on SDN and network slicing capability.

5 5G Key Technologies and Networking Architecture

5.1 New Radio

The overall protocol of NR is based on LTE with enhancement and optimization. For user plane, SDAP sublayer is added, while functions of PDCP and RLC sublayer are optimized to reduce delay and enhance reliability. For control plane, RRC_INACTIVE state is added to RRC sub-layer, which benefits the energy saving of terminals and reduces the control plane delay. In the physical sublayer, the design of NR reference signals is optimized, and more flexible waveform and frame structure parameters are adopted to reduce overhead. The design of NR protocol is forward compatible and meets the requirement of diverse usage scenarios.

NR adopts LDPC code which can be parallel decoded for data channel, and mainly uses Polar code for control channel for eMBB. The channel coding adopted by NR has better theoretical performance with lower delay and higher throughput.

Different from LTE uplink, which only uses DFT-S-OFDM waveform, NR uplink waveform could be adaptively transformed between CP-OFDM waveform and DFT-S-

OFDM waveform according to channel state. CP-OFDM waveform is a multi-carrier transmission technology with more flexible scheduling. It is suitable for cell center users due to the better link performance in high signal-to-noise ratio environment.

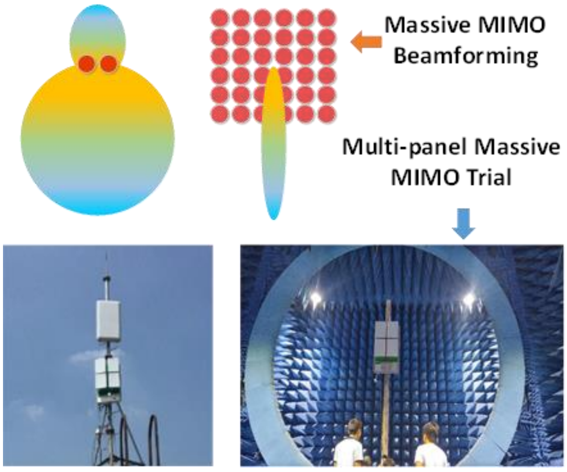
Compared with LTE adopting relatively fixed air interface parameters, NR designs a set of flexible air interface parameters to adapt various usage scenarios through different parameter configurations. Different subcarrier spacing can realize slot/mini-slot with different length. The symbol in a slot/mini-slot includes downlink, uplink and flexible symbol with static, semi-static or dynamic configuration.

NR cancels the cell-level reference signal CRS in LTE while keeping the UE-level reference signal DMRS, CSI-RS and SRS, and introduces PTRS for the phase noise in the high frequency scenario. The main reference signals of NR only transmit in the connection mode or scheduling occasions, which reduces the energy consumption and networking interference and is more suitable for the multi-antenna port transmission of massive MIMO system.

From the perspective of 3GPP protocol, the design of NR air interface is flexible. However, considering the terminal implementation and networking complexity, it is necessary to refine out a simple and feasible solution according to usage scenarios and frequency resources in actual deployment.

5.2 Massive MIMO

5G base station will support large-scale antenna array with hundreds of antennas and dozens of antenna ports, and through MU-MIMO technology to support spatial multiplexing transmission with larger capacity. The 5G system spectrum efficiency and user experience in the large capacity scenario with high user density are improved. Massive MIMO system can also control the phase and amplitude of transmission or reception signal in each antenna channel and produce directional beams. Consequently, beamforming gain is achieved which can be used to enhance cell coverage.



Fiugre 2 Massive MIMO Technology and Test

Large-scale antenna array can also be used for millimeter wave, through beamforming, beam scanning, beam handover technologies to compensate additional transmission loss. Massive MIMO also needs to use digital-analog hybrid architecture to reduce the number of millimeter wave RF elements.

Massive MIMO enables higher performance, but the cost, volume and weight of large-scale antenna also increase significantly compared with traditional passive antenna. From the perspective of the operator, China Telecom has completed research and test of the first modular massive MIMO prototype, focusing on problems such as large volume, heavy weight, difficult to test, deploy and maintain, etc. The modular large-scale antenna can easily compose different forms for diverse usage scenarios and reduce operation cost with advantages of easy installation, deployment and maintenance. Currently, 3GPP organization has completed the codebook design of modular large-scale antenna and will push forward industrialization of massive MIMO. China Telecom is more inclined to use 64-port massive MIMO with 192 oscillators to satisfy higher capacity, due to the 1.7dB coverage enhancement compared with 128 oscillators.

5.3 Spectrum

In the 5G era, spectrum resources will be more insufficient. According to the features of frequency bands, sub-6GHz spectrum will meet both demands of coverage and capacity, which are a tradeoff between peak data rate and coverage.

At present, 14 countries/regions have announced plans to auction or allocate sub-6GHz spectrum bands, and 6 countries/regions have announced plans to auction or allocate above 6GHz spectrum bands.

Table 1 Planned 5G spectrum auctions/allocatoins (GSA 2018/1)

Frequencies proposed or being (formally) considered, or licensed for 5G	Country/Region
Sub-6GHz	Australia, Czech Republic, France, Hong Kong, Latvia, Mexico, Netherlands, Poland, South Korea, Spain, Switzerland, Thailand, United Kingdom, United States
Above 6GHz	Australia, Canada, Hong Kong, Poland, South Korea, United States

Sub-6GHz bands are relatively more mature in the standardization and industrial chain, which will benefit the deployment of 5G network in the early stage. China Telecom is actively participating in research on the expansion of the 5G spectrum bands.

5.4 CU/DU RAN architecture

To carry 5G applications, the functionality of the 5G BBU will be reconstructed as two functional entities: Centralized Unit (CU) and Distributed Unit (DU). RF unit, some baseband physical layer functions and antennas form AAU. The innovative design could better facilitate radio access network (RAN) virtualization.

According to 3GPP, radio protocol functions above PDCP are provided in CU and radio protocol functions below PDCP are provided in DU. CU and DU as RAN logical function nodes can be mapped to different physical entities or one physical entity. CU/DU split is good for small packet mMTC service, but standardization procedure has not yet started. In terms of CU/DU deployment strategy, China Telecom will deploy co-located CU/DU in the initial stage with benefits of fewer network elements, lower complexity of planning and operation, faster construction, lower cost deployment and smaller latency. In the long run, according to the requirements of the service scenarios, it may gradually evolve to an architecture of three layers of separated CU/DU/AAU. Therefore, co-located CU/DU equipment is required to be modular designed, which is easy to realize a CU/DU split architecture in the future. At the same time, issues such as improving general platform forwarding capabilities, coordinating with existing network management, and further optimizing of the mobility management standard process under the CU/DU separation scenario need to be resolved.

The interface between DU and AAU is varied among vendors, which is hard to be standardized. Currently, there are two main deployment solutions: CPRI and eCPRI. With the traditional CPRI interface, the fronthaul data rate requirement is basically linear with the number of AAU antenna ports. Taking 100 MHz/64-port/64QAM as an example, 320 Gbps is required. Even considering 3.2 times compression, the data rate is over 100 Gbps. With the eCPRI interface, the data rate requirement is basically linear with the number of flows supported by the AAU. Under the same conditions, the data rate requirement will drop below 25 Gbps. Therefore, the eCPRI is preferred for DU and AAU interfaces.

5.5 Service-based architecture and capability exposure

5GC architecture introduces some new features to achieve flexible, efficient and open network, including control and forwarding separation, modular design of network functions, service-based interface, enhanced capability exposure, etc.

5GC achieves complete separation of control plane and user plane. The control plane can be centrally deployed and allows global scheduling of forwarding resources. The user plane can be centrally deployed or distributedly deployed on demand. Meanwhile it realizes local traffic offloading and support millisecond level end-to-end latency when deployed close to network edge.

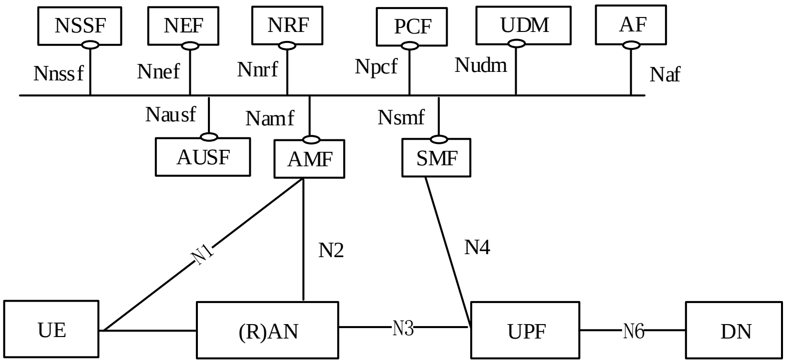


Figure 3 5G Service-based Architecture

5GC introduces serviced-based design to describe network functions of control plane and interface intercommunication. Service module can independently register, publish and discover to avoid the complex intercommunication in traditional tight-coupled module. 3GPP specification adopts TCP/TLS/HTTP2/JSON protocol to enhance flexibility and scalability of the network.

Enhanced service environment of capability exposure is one of the 5GC new features. NEF is the basic network function of capability exposure. NFV-based orchestration capability is an important capability set in 5G network while orchestration capability exposure can be used for 5G business model innovation.

The introduction of service-based architecture also brings new challenges. For example, it is more complex to manage 5GC due to flexible service orchestration and more accurate collaboration management. Compared with traditional intercommunication protocols, service-based interface has larger overhead, more frequent interactions caused by state-less processing, and increased delay, IO and processing load. The increased functions of 5GC network elements makes it more difficult to debug and verify the interface.

Further research will focus on 5GC networking scheme of supporting multi-access convergence and evaluate the performance of 5GC with service-based architecture.

5.6 4G and 5G interworking

3GPP proposed a variety of 4G and 5G interworking solutions, including 5G SA and 5G NSA. The full Release 15 specification is frozen in June 2018. In SA, 5G NR is accessing 5GC with control signaling independent of 4G network, and 4G and 5G networks are coordinated through core networks. 5G SA provides new features including network slicing, MEC, flexible session and dynamic QoS. For 4G network, MME must be upgraded to support N26 interface. 4G base stations need to be configured with 5G handover parameters. 4G and 5G base station vendors can be different. terminals are not required to support dual connectivity.

NSA utilizes the existing 4G base station as an anchor for control signaling, and core network can be EPC or 5GC. In NSA network, vendors must be the same in the same area, and terminals must support dual connectivity.

The release of NSA based on EPC is finalized in December 2017, which does not support network slicing, MEC and other features. EPC needs to be upgraded to support the requirements of 5G access. 4G base station needs to be upgraded to support X2 interface between 4G and 5G base stations. The release of NSA based on 5GC will be frozen in December 2018. In this case, 5G network can support network slicing, MEC and other new features. 4G base station needs to be upgraded to support 5G protocol.

The selection of 4G/5G interworking solution should consider network construction plan, user experience, service capabilities, terminal ecosystem and complexity of networking.

- 5G will eventually move to SA. Both SA and NSA support 4G and 5G interworking but choosing SA can avoid frequent network upgrade.
- SA network requires less upgrade. NSA based on EPC requires frequent network upgrade to evolve to SA. For NSA based on 5GC, LTE eNBs need to be upgraded to eLTE. In this case, 4G and 5G dual connectivity is hard to be realized between different vendors.
- SA network can provide more new services. Network slicing, MEC and customized user experience for enterprise and vertical industries can be provided.
- Terminal for SA network is lower-cost. In NSA network, terminal will be more difficult to design and expensive to mitigate serious interference at 3.5GHz.

In SA network, terminals are easier to be manufactured with lower cost.

Based on the above facts, China Telecom is more inclined to adopt the standalone route, with 5G and 4G co-existing for a considerable period.

Given the difficulty of 5G full national coverage in the early stage, VoLTE solution will be used to guarantee voice service continuity when SA-based 5G fall back to 4G. Then, VoNR solution may be considered when 5G coverage is good enough and profitable business models emerge.

5.7 Multi-network convergence

As a network with convergence of multiple access technologies, 5G should follow multi-network collaboration principle. That is, 5G, 4G, WLAN and other networks jointly achieve indoor and outdoor network collaboration while avoiding interruption and missing of current network services.

In traditional multi-network convergence, the control entity is in core network and realizes fundamental convergence capabilities such as unified authentication, billing and handover management, etc. However, access network only provides auxiliary convergence policy information and network selection of terminals only depends on radio signal strength. It is difficult to implement flexible selection of network based on dynamic network information (e.g. network load, link quality and backhaul load) or service types.

China Telecom has carried out research on “application awareness interworking between LTE and NR”, by allowing full play to 5G advantages and effectively exploiting existing 4G investment to maximize network value while guaranteeing service capability and user experience. From the perspective of network evolution and user experience, it is proposed to perceive applications and user QoE to select, handover or reselect 4G/5G network. China Telecom will aggressively promote 5G network evolution based on application aware.

5G and WLAN convergence can adopt converged architecture in access network. That is, WLAN accesses to 5G RAN and forwards traffic to UE. WLAN can also access to 5G core network and obtain user data directly. Additionally, compared with the seamless coverage of 4G, 5G will be coverage limited in initial deployment. Further research should be focus on connection enhancement method of 5G and WLAN convergence.

5.8 Multi-access edge computing

By moving capability of computing, storage and service to network edge, MEC enables application, service and content to achieve localized, close-to-user and distributed deployment. Meanwhile, MEC fully exploits network data to perceive and analyze network context and open these contexts to the third party applications, effectively improving network intelligence level and promoting the deep convergence of network and service.

Multiple networks such as mobile and fixed network will co-exist in 5G era. To relieve the pressure on backhaul caused by network traffic and ensure the same user experience among multiple networks, China Telecom will construct a unified MEC to achieve edge convergence of fixed and mobile network by exploiting the advantages of existing fixed network resources (transmission and CDN), as shown in figure 4.

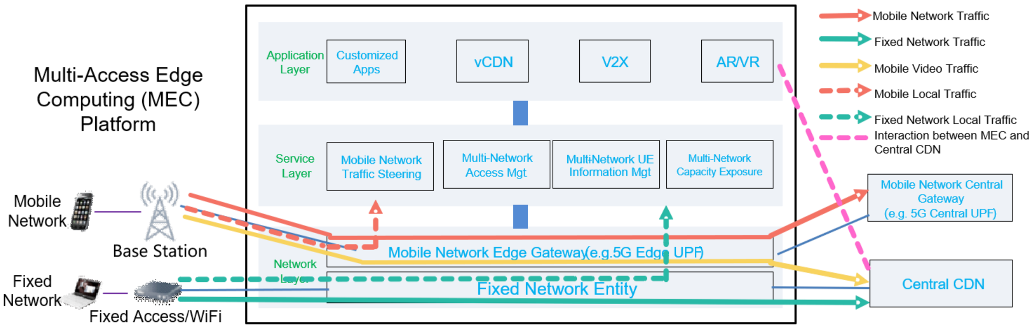


Figure 4 FMC-oriented MEC architecture

MEC needs to support multiple access simultaneously such as mobile network, fixed network, WLAN etc. The edge gateway of 5G network can be achieved through moving UPF to the edge of the local network. The platform can flexibly route traffic to different networks according to service types or requirements, which can relieve the burden of backhaul and realize the FMC-oriented multi-network collaborative bearer. Meanwhile, it improves user experience among multiple networks and achieves intelligent distribution of content by sharing the edge CDN resources between multiple networks. Additionally, MEC provides deployment and operation environment for localization of new applications with low latency, large bandwidth and high computation complexity and meets the requirements of unified communication and customized services of the enterprise.

For URLLC services, MEC should be closer to network edge to minimize the transmission delay to millisecond level.

MEC deployment policy should depend on delay and coverage demands of applications and deploy MEC on the appropriate hierarchy of the data center, including metropolitan core DC, edge DC and even access office.

5.9 Network slicing

Network slicing is a key enabler for 5G network. China Telecom will use logical or physical multi-grained network slicing to meet the specific needs of different business models and vertical industries.

A network slice is an end-to-end logical subnet. It requires coordination of core network (control plane and user plane), RAN, IP bearer network, and transport network. Network slices can use isolated resources and/or shared resources. The control plane for network slicing is deployed in a service-based architecture. According to the service requirements for forwarding performance, the user plane uses software forwarding acceleration and hardware acceleration to achieve the balance of user plane deployment flexibility and processing performance. Wireless network slicing should focus on the efficiency of resource block while ensuring that key objectives such as spectrum efficiency, system capacity, and network quality are not affected. With flexible frame structure, QoS and RAN parameters reconfiguration, operator can provide differentiated slicing functions.

The 3GPP-defined network slice management functions include communication service management, network slice management, and network slice subnet management. The communication service management function implements mapping of service requirements to network slice requirements. The network slice management function implements slice orchestration and management and decomposes the entire network slicing SLA into different slice subnets (e.g., core network slices, RAN slices, bearer network slices). The network slice subnet management function maps SLAs to network service instances and configuration requirements and send them to MANO. Resource scheduling of the bearer network will be achieved through cooperation with its management system.

E2E network slicing is a foundation to support diversified 5G services and is fundamental to 5G network architecture evolution. China Telecom will focus on network slicing and its applications, also strengthen the design, layout, and management of network slicing, such as the coordination of network slicing management/network slicing subnet management with MANO and bearer network.

5.10 5G bearer network

The bearer network should meet the requirements of high data rate, low latency, high reliability, and high-precision synchronization of the 5G network, and support the flexible networking, network slicing, intelligent management and coordination.

The 5G bearer network should follow the principles of fixed mobile convergence, comprehensive bearer, and sharing resources such as telecom room infrastructures and bearer equipment as much as possible, to achieve rapid deployment at low cost and form a differentiated competitive advantage for China Telecom.

The optical fiber cable network shall be planned and constructed according to the user density and service requirements and shall become a unified physical bearer network for fixed network and mobile network. China Telecom FTTx access network mainly uses ring (access backbone) + tree (distribution+ drop) topology and makes full use of existing optical fiber resources to achieve fronthaul and backhaul.

Based on the 5G RAN architecture, the 5G bearer network consists of the following three parts:

- Fronthaul (AAU-DU): transmit data between AAU and DU;

- Middlehaul (DU-CU): transmit data between DU and CU;
- Backhaul (CU-core network): transmit data between CU and core network.

Due to CU/DU co-located solution is preferred in the initial stage of 5G RAN, the 5G bearer network will focus on the fronthaul and backhaul, as shown in Figure 5. And, eCPRI-based fronthaul is a prior consideration.

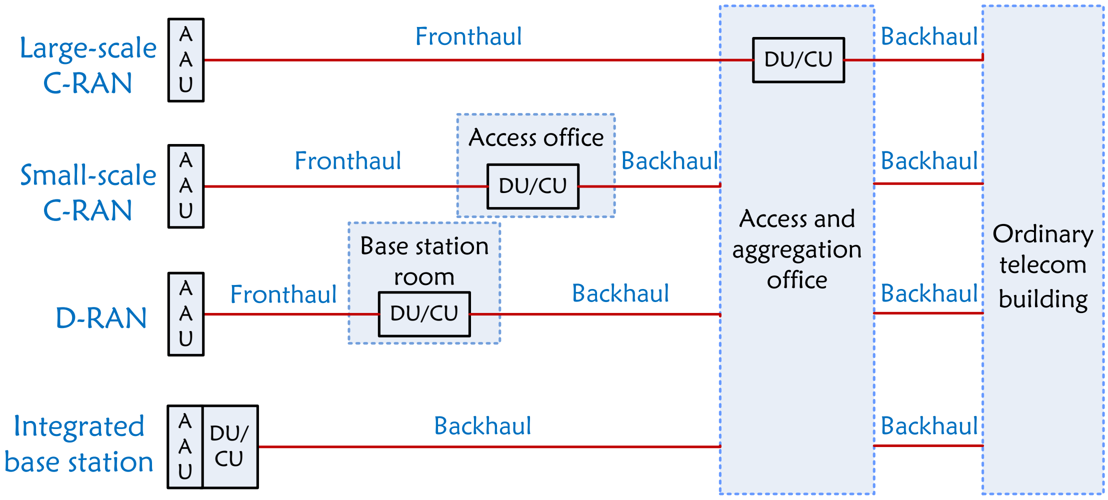


Figure 5 Bearer network segmentation for different RAN deployment architectures

Considering the structure of China Telecom's local optical fiber cable network and the base station layout, the 5G RAN can be deployed in the following three modes:

- Large-scale C-RAN: The CU/DU are deployed together in the ordinary telecom building/access and aggregation telecom room. The number of base stations connected to a large concentration point is usually 10 to 60.
- Small-scale C-RAN：The CU/DU are deployed together in the access office. The number of base stations connected to a small concentration point is generally 5 to 10.
- D-RAN: The CU/DU are distributedly deployed in macro base stations, with 1 to 3 base stations accessed.

At present, more than half of the base stations of China Telecom's 4G network adopt the BBU centralized deployment, which gives us sufficient experience in construction and maintenance of this deployment mode. In actual deployment, the economics of the construction and the convenience of operation and maintenance should be evaluated based on the existing optical fiber resources and telecom room conditions, and then make a choice between concentrated and distributed CU/DU. Under the premise of sufficient resources and ensuring reliability of wireless network, C-RAN is preferred to save the operational cost, realize rapid deployment of base stations, and improve inter-base station cooperation efficiency.

For C-RAN scenario, China Telecom shall encourage vendors to develop high density DU equipment to save space and reduce interconnection fibers and optical interfaces. At the same time, it also needs to guarantee the reliability of the equipment.

In the 5G network, synchronization signal needs to be transmitted to the AAU. For cost reasons, the clock source is expected to be deployed in the DU or even higher position of the network, so the fronthaul and backhaul bearer must consider the transmission requirement of the synchronization signal. Currently, SyncE, IEEE 1588, and other synchronous transmission technologies can meet the 5G basic service synchronization accuracy requirement (1.5us). Solutions for inter-site collaboration and other high-precision synchronization requirements (indicators to be determined) need further study.

5.10.1 Fronthaul solution

In a scenario where the optical fiber resources are sufficient, or D-RAN is deployed, the 5G fronthaul is mainly based on point to point optical fiber connection. In a scenario where the optical fiber resources are insufficient, or C-RAN is deployed, WDM bearer technology is preferred.

Fiber connection shall use BiDi technology，which can save 50% optical fiber resources and provide guarantees for high-precision synchronous transmission.

WDM is a proper technology to save fiber resources, which mainly includes passive WDM, active WDM/M-OTN and WDM PON. (1) Passive WDM: Install the colored light module on the AAU and DU devices, and achieve WDM functions through passive splitter/combiners, which is less expensive, but maintenance ability is weak. (2) Active WDM/M-OTN: Connects AAUs and DUs to WDM/M-OTN devices, implements maintenance and management through M-OTN overhead, and it can provide protection switching capability; (3) WDM-PON: In an FTTx point-tomultipoint topology, the AAU is connected to a separate ONU device or an embedded modular ONU (SFP+ module), and the DU is connected to the OLT.

5.10.2Backhaul solution

For 5G backhaul, in the early stage, considering that the traffic is relatively light, relatively mature IPRAN solution is suggested. Later, based on the service development, OTN can be used in heavy traffic areas. PON technology can be used as a supplement in some scenarios.

IPRAN reuses the 4G backhaul network architecture to support Layer 2 and Layer 3 flexible networking functions. It has many advantages including a well-developed industrial chain, cross-manufacturer networking (in the same ring) capabilities, and support of unified bearer of 4G/5G services. IPRAN can meet 5G requirements through capacity expansion or upgrade. High-data-rate interfaces (such as 25GE/50GE) can be considered in backhaul access layer on demand. FlexE can be introduced to support network slicing. To further simplify the control protocols and enhance the flexible scheduling capabilities, the EVPN, SR and SDN architecture can be used to optimize automatic service provisioning and flexible adjustment. In long-distance transmission scenarios, wavelength connection can be provided for IPRAN using WDM/OTN.

OTN can provide high data rate. Based on the existing ODUk hard pipe and Ethernet/MPLS-TP packet processing capabilities, the industry is studying to further enhance the routing function to meet the end-to-end flexible networking requirements of 5G bearer. For deployed packet-enhanced OTN equipment based on the unified cell switching, the enhanced routing function can reuse the existing switching card, but it is necessary to develop a new type of routing card and upgrade the main control card. The OTN solution can support tree topology by breaking the ring and configuration of wavelength or ODUk fast channel to ensure high data rate and low latency of 5G services. ITU-T is studying the simplified encapsulation of M-OTN and 25G/50G FlexO interfaces to reduce the delay and cost of OTN equipment.

The PON solution is applicable to the backhaul scenarios where CU/DU is co-located with AAU or CU/DU/AAU is integrated, which needs to support 10 Gbps and above. ODN and OLT equipment of the FTTH network can be used to realize low-cost and quick deployment.

5.10.3 Core network bearer solution

Compared to the 4G core network, due to network cloudification and introduction of MEC, the main functions of the 5G core network are deployed in the regional DC at the provincial center, and some functions will be moved to the metropolitan area network, including the metro core DC, edge DC, and even in the access office, which requires the bearer network to provide flexible routing functions. The interconnection of 5G core network elements inside one province is provided by the backhaul network. The inter-provincial connections need to be considered together with the DC interconnection network.

5.11 Artificial Intelligence-powered 5G

Currently, data-driven AI field are facing great development opportunities and focused by various industries. The 5G network architecture must be able to provide sufficient flexibility, scalability, and programmability to meet different service needs, which brings new challenges to the traditional way of relying heavily on manual network deployment and operation. Therefore, mobile network in the 5G era can use AI to change the network operation model and achieve intelligent 5G.

In the 5G era, AI can be used to change the network operation model in terms of network management, resource scheduling, energy conservation and edge computing, and promote the realization of intelligent 5G.

- Intelligent network slicing management: According to the prediction of user behavior patterns, traffic models, and network status, operator can implement flexible real time and firm-real time orchestration of network resource and intelligent network slicing scale-in and scale-out.
- Intelligent network resource scheduling and configuration: AI can automatically identify 5G coverage scenarios such as stadiums, business

districts, and train stations, and make predictions through traffic models, user distribution, and other parameters, and then give optimal RAN parameter configuration. Ultimately, operator can implement self-optimizing configuration of 5G network, and effectively improve resource utilization and user experience.

- Intelligent 5G energy conservation：Through statistical correlation analysis of user behavior, service characteristics, traffic model, network coverage, and other data, the idle time and busy time of the base stations can be accurately predicted. Also, based on the actual network status and prediction results, automatic sleep and wake-up operations of 5G base stations can be realized and energy conservation of servers can be achieved while meeting service needs.
- Intelligent 5G edge computing: AI-powered MEC at the edge of 5G network can provide AI operation and analysis capabilities for 5G local applications. For example, video analysis and image recognition have been widely used in security, product testing, refined production operations, and medical care.

6 Summary and Prospect

To fulfill the 5G development target of China, China Telecom will conduct research, launch trials and provide innovative applications according to national strategy. As an integrated intelligent information service operator, China Telecom will cooperate with all partners to jointly establish a collaborative, innovative and win-win 5G ecosystem.

In 5G era, China Telecom is committed to build a unified information infrastructure platform based on 5G network for all walks of life. China Telecom is working tirelessly to implement national strategies of “Network Powerful Nation” and “Internet+”, and push forward “informatization drives industrialization, industrialization promotes informatization”. China Telecom will pursue the target of smart age and a better life.

Abbreviations

5GC	5^{th}-generation Core
AAU	Active Antenna Unit
ADC	Analog-to-Digital Converter
AI	Artificial Intelligence
AR	Augmented Reality
ARPU	Average Revenue Per User
BBU	Baseband Unit
BiDi	Bi-Directional
CDN	Content Delivery Network
CP-OFDM	Cyclic Prefix Orthogonal Frequency Division Multiplexing
CPRI	Common Public Radio Interface
C-RAN	Centralized RAN
CRS	Cell Reference Signal
CSI-RS	Channel Status Information-Reference signal
CU	Central Unit
DAC	Digital-to-Analog Converter
DC	Data Center
DFT-S-OFDM	Discrete Fourier Transform-Spread-Orthogonal Frequency Division Multiplexing
DMRS	Demodulation Reference Signal
D-RAN	Distributed RAN
DU	Distributed Unit
eCPRI	Enhanced Common Public Radio Interface
eLTE	Evolved LTE
eMBB	enhanced Mobile Broadband
EPC	Evolved Packet Core
EVPN	Ethernet Virtual Private Network
FlexE	Flexible Ethernet
FlexO	Flexible Optical Transport Network
FTTH	Fiber To The Home
FTTx	Fiber To The X
GaN	Gallium Nitride
GPS	Global Positioning System

HARQ	Hybrid Automatic Repeat reQuest
HTTP	HyperText Transfer Protocol
IMT	International Mobile Telecommunications
JSON	JavaScript Object Notation
LDPC	Low Density Parity Check Code
LTE	Long Term Evolution
MAC	Media Access Control
MANO	Management and Orchestration
MIMO	Multiple-Input Multiple-Output
MEC	Multi-access Edge Computing
MME	Mobility Management Entity
mMTC	massive Machine Type Communications
M-OTN	Mobile-optimized Optical Transport Network
MPLS	Multi-Protocol Label Switching
MU-MIMO	Multi-User Multiple-Input Multiple-Output
NEF	Network Exposure Function
NFV	Network Function Virtualization
NFVI	NFV Infrastructure
NR	New Radio
NSA	Non-Standalone
ODN	Optical Distribution Network
ODUk	Optical Channel Data Unit-k
OLT	Optical Line Terminal
ONU	Optical Network Unit
OTN	Optical Transport Network
PDCP	Packet Data Convergence Protocol
PHY	Physical Layer
PON	Passive Optical Network
PTRS	Phase-tracking reference signals
QAM	Quadrature Amplitude Modulation
QoE	Quality of Experience
QoS	Quality of Service
RAN	Radio Access Network
RAT	Radio Access Technology

RLC	Radio Link Control
ROI	Return On Investment
RRC	Radio Resource Control
SA	Standalone
SDN	Software Defined Network
SFP	Small Form-factor Pluggable
SLA	Service Level Agreement
SR	Segment Routing
SRS	Sounding Reference Signal
SyncE	Synchronous Ethernet
TCP	Transmission Control Protocol
TLS	Transport Layer Security
UE	User Equipment
UPF	User Plane Function
URLLC	Ultra-Reliable and Low Latency Communications
VIM	Virtualised Infrastructure Manager
VNFM	VNF Manager
VoLTE	Voice over LTE
VoNR	Voice over NR
VR	Virtual Reality
WDM	Wavelength Division Multiplexing
WLAN	Wireless Local Area Network