White Paper of
Next Generation Fronthaul Interface

Version 1.0
June 4, 2015

China Mobile Research Institute
Alcatel-Lucent
Nokia Networks
ZTE Corporation
Broadcom Corporation
Intel China Research Center

Contact: Huang Jinri
Email: huangjinri@chinamobile.com

Yuan Yannan
Email: yuanyannan@chinamobile.com
# Contents

**FOREWORD** ........................................................................................................................................... 1

1 **OVERVIEW** ......................................................................................................................................... 3

   1.1 CHALLENGES FACED BY EXISTING NETWORKS ........................................................................... 3
   1.2 FUTURE NETWORK NEEDS ............................................................................................................... 3
   1.3 ABOUT THIS WHITE PAPER .......................................................................................................... 4

2 **NGFI: DEFINITION, ADVANTAGES AND SCENARIOS** ................................................................. 5

   2.1 DEFINITION OF NEXT-GENERATION FRONTHAUL INTERFACE ............................................... 5
   2.2 PRINCIPLES FOR NGFI DESIGN .................................................................................................... 6
   2.3 NGFI LOGICAL LAYERS .................................................................................................................. 7
   2.4 ADVANTAGES OF NGFI .................................................................................................................. 8
   2.5 NGFI APPLICATIONS ...................................................................................................................... 8

3 **POTENTIAL NGFI DESIGNS** ......................................................................................................... 10

   3.1 POSSIBLE DIVISIONS OF THE RCC-RRS INTERFACE ................................................................ 10
   3.2 TRANSMISSION AND PROCESSING DELAY ALLOCATION SOLUTION ANALYSIS .................. 20
   3.3 CONVERGENCE RATIO OF STATISTICAL MULTIPLEXING ANALYSIS ..................................... 21
   3.4 SUMMARY OF SCHEMES ............................................................................................................. 25

4 **MAJOR CHALLENGES AND KEY TECHNOLOGIES FOR REALIZATION OF NGFIS** .............. 27

   4.1 RCC-RRS FUNCTION PARTITIONING .......................................................................................... 27
   4.2 WIRELESS DATA PACKETIZATION .............................................................................................. 27
   4.3 MAIN CHALLENGES OF NGFI TRANSMISSION ........................................................................ 28
   4.4 IMPACT OF INTRODUCING NGFIS .............................................................................................. 30

5 **DEFINITION OF NGFI REQUIREMENTS** ....................................................................................... 32

   5.1 NGFI WIRELESS INTERFACE REQUIREMENTS ......................................................................... 32
   5.2 NGFI FRONTHAUL NETWORK LOAD REQUIREMENTS ............................................................. 33
   5.3 EQUIPMENT CONFIGURATION REQUIREMENTS ........................................................................... 34

6 **SUMMARY** ......................................................................................................................................... 35

**ABBREVIATIONS** ............................................................................................................................... 37

**REFERENCES** ....................................................................................................................................... 38

**ACKNOWLEDGMENTS** ....................................................................................................................... 39
FOREWORD

In recent years, C-RAN (Centralized, Cooperative and Clean Cloud Radio Access Network), with centralized BBU (Base Band Units) and RRU (Remote Radio Units), has been deployed more and more widely in many countries and regions around the world, although it is affected by CPRI (Common Public Radio Interface) limitations and the high bandwidth requirements of existing BBU/RRU interfaces. If CPRIs continue to be used for fronthaul networking, it will limit the deployment of C-RAN on a larger scale. Furthermore, future-oriented 4.5G and 5G wireless technologies present new challenges with respect to existing CPRIs. This white paper resolves these problems by proposing NGFIs (Next Generation Fronthaul Interfaces) and lists a variety of optional solutions for interface function splitting. Its overall purpose is to encourage discussion between industry stakeholders, form an industry consensus, promote the maturity of NGFIs and facilitate the future development of wireless networks.

This white paper covers the evolving demand for NGFIs, design principles, application scenarios, potential solutions and other technical aspects with respect to NGFIs, providing a valid reference for the future evolution of wireless access networks. It is hoped that it will promote the NGFI framework concept, while also providing reference indicators for the design of future transmission equipment. We are extremely grateful to Alcatel-Lucent, Nokia Networks, ZTE Corporation, Broadcom Corporation, the Intel China Research Center and other organizations for their efforts in writing this document. This first edition of the NGFI White Paper contains numerous technical points that are yet to be developed, and we welcome feedback from the industry with a view to eliciting additional technical opinions with which to enrich and expand the contents.
1 OVERVIEW

1.1 Challenges Faced by Existing Networks

The centralized BBU deployment advocated by C-RAN offers significant advantages, including accelerated network deployment, reduced operating and investment costs, effective support for cooperative technologies, carrier aggregation and other key LTE-A technologies, as well as improved network performance[1]. However, fronthaul networks constitute a major challenge to C-RAN deployment. Taking LTE as an example, CPRI interfaces have high bandwidth and low delay requirements; although using active or passive WDM technology as a basis can effectively resolve the fronthaul problem and save fiber, it also introduces additional transmission equipment, resulting in rising costs. Therefore, if a more flexible, low-bandwidth fronthaul network can be designed, it would further resolve C-RAN networking transmission problems. In addition, the need for dual-routing protection resulting from C-RAN centralization also necessitates flexible routing between BBU pools and RRUs. In short, traditional CPRIs will struggle to support the future networking demands of centralized WLAN deployment.

Regarding the efficiency of traditional CPRIs in carrying mobile communication data, it is clear that mobile communication services are highly dynamic by nature, insofar as office buildings, residential areas and other areas exhibit a tidal effect, with most networks in a low-traffic load condition during the early morning period. However, the fixed-rate front-end CPRI or OBSAI (Open Base Station Architecture Initiative) transmission interface adopted by existing BBUs and RRUs is a fixed-rate fronthaul interface based on the TDM (time-division multiplexing) protocol, which transmits CPRI/OBSAI streams even in the absence of traffic load and therefore renders data transmission inefficient [2].

1.2 Future Network Needs

Regarding the functional and structural evolution of existing wireless networks, currently, 3GPP has introduced LTE-based dual connectivity into R12, and discussions are underway for R13 to provide a heterogeneous dual connectivity function in LTE + Wi-Fi heterogeneous networks. The introduction of ultra-dense, flexible, small-cell deployment is required to further meet the future x1000 capacity and density requirements of 5G. Ultra-dense, small-cell deployment is bound to create problems involving frequent switching between cells and signal interference. These problems must be resolved through a centralized control plane, as well as closer air interface coordination between macro cells and small cells. Thus, it is apparent that network structures are moving toward C/U separation and centralized control. Consequently, fronthaul interfaces need to provide low delay and high-bandwidth transmission services and meet the evolving demand for wireless network architecture by means of BBU/RRU function remodeling.

In terms of the demand for future wireless networks to evolve toward 5G, the 5G era will not only continue to support existing network applications, but it will also introduce many new user applications. For example,
pervasive HD/ultra-high definition and even 3D holographic film and video in dense urban areas, 50+ Mbps high-speed experience for all users, high-mobility applications at speeds over 350 km/h, sensor networks, touch Internet, e-health, natural disaster monitoring and so on[3]. To meet the demand for a 5G diversified service scenario, future networks must have rapid customization and deployment capabilities. Therefore, they must support large-scale RAN sharing functions, which means that fronthaul networks must have greater flexibility and scalability.

The introduction of new 5G network technology will lead to the proliferation of new technologies and functions that increase user bandwidth, network capacity, service delay and other performance aspects to meet the demand for the new applications[4]. First, as wireless bandwidth and antenna numbers increase, transmission bandwidth between existing BBUs and RRUs increases dramatically. By reclassifying BBU/RRU functions, it is possible to meet the front-end transmission requirements of network massive MIMO and other new technologies. Second, for high-level services requiring low delay and high bandwidth, there is a clear trend toward service sinking and marginalization of core network functions. Taking service hit rate into account, sinking services to BBU centralized deployment is a compromise between service hit rate and service delay requirement. In this scenario, high-bandwidth, low-latency, fronthaul networks provide the basis for meeting demand for higher-level services.

Based on the above, we believe that the CPRI/OBSAI interface that is universally applied throughout the industry is primarily applicable to peer-to-peer connections. Due to disadvantages such as low transmission efficiency, poor flexibility and poor scalability, and particularly due to the high cost of centralized deployment, it is unable to meet the evolving need for 5G-oriented fronthaul networking.

To increase the efficient use of network resources and better support the evolution of wireless networks toward 5G systems, as well as to better support BBU centralized deployment, we must redefine the functionality of BBUs and RRUs and design a BBU and RRU interface based on packet transmission technology, i.e. NGFI, in order to meet the challenges of continuously evolving networks.

1.3 About this White Paper

This white paper sets out China Mobile’s vision for “Next Generation Fronthaul Interfaces (NGFI)” and presents the major technical challenges of NGFIs, outlining a research framework and defining key demand indicators. We invite the industry and academic research institutions to actively participate in the study of NGFI key technologies and jointly promote the corresponding process of standardization and industrialization.

This first edition of the white paper may not be sufficiently comprehensive and may contain some inconsistencies, so proposed amendments and suggestions are welcome. Over time, new research may be incorporated into subsequent editions.
2 NGFI: DEFINITION, ADVANTAGES AND SCENARIOS

2.1 Definition of Next-Generation Fronthaul Interface

NGFI is the fronthaul interface between baseband processors and remote radio heads for the next generation of radio network infrastructure. NGFI is an open interface possessing at least two key properties. First, it redefines the functions of baseband units (BBUs) and remote radio units (RRUs). Some BBU processing functions are shifted to the RRU, which leads to a change in BBU and RRU architecture. As a result, the BBU is redefined as the Radio Cloud Center (RCC), and the RRU becomes the Radio Remote System (RRS). Second, the fronthaul changes from a point-to-point connection into a many-to-many fronthaul network, using a packet exchange protocol. In addition, NGFI should, as a minimum requirement, comply with basic principles: adaptive bandwidth changes responsive to statistical multiplexing and payload; maximum support for high-gain coordinated algorithms; interface traffic volume decoupled from the number of antennas at RRU; neutrality with respect to air interface technology; optimization of RRS-RCC connections; and others. NGFI will affect the architecture of radio equipment and will create new demands on NGFI carrier networks.

![Figure 2-1: C-RAN Radio Network Architecture Based on NGFI](image)

As Figure 2-1 shows, the NGFI fronthaul network connects to the RRS and RCC.
The remote radio system (RRS) includes the following functions: antenna, RRU, and radio aggregation unit (RAU, traditionally part of the BBU’s baseband processing). In terms of current network architecture, RRUs will be positioned in existing base stations, and their coverage will be equivalent to a metrocell or metrocell+remote radio head deployment. The RAU shown in the figure is a function. The distribution of physical equipment depends on the architecture of each specific network: it may be combined with the RRU or instantiated in a separate piece of physical equipment.

The RCC incorporates the old BBU functions minus radio aggregation; and higher control functions. It handles multiple base stations, carrier waves and cells, so it serves as a function pool. This centralized functional unit provides coverage of the areas covered by all its downstream RRUs. This inclusion of a centralized baseband processing unit does not mean reversion from flat LTE network design to a multiple layer network. Rather, it is restructuring of functions between the BBU and RRU, in consideration of future demand for more highly cooperative algorithms. It has no impact on the flat LTE network architecture.

The NGFI links the RRS and RCC functions. That is, it is the interface between the restructured baseband processing and remote radio functions. Its design parameters must consider the new demands that this revised structure places on bandwidth, delay and synchronization.

2.2 Principles for NGFI design

2.2.1 Statistical multiplexing

Statistical multiplexing means that, within a particular network segment (e.g., 100 or 1000 carrier waves), statistical multiplexing is applied to the fronthaul bandwidth between RCC and RRS. This reduces the total fronthaul bandwidth required, allowing better cost control.

2.2.2 Adaptive bandwidth modulation in response to payload

Adaptive response to payload means that the NGFI bandwidth varies in proportion to the level of traffic in the layer above. Adaptive response to payload is one of the conditions required for statistical multiplexing.

2.2.3 Maximum support for high-gain coordinated algorithms

Given the three conditions above, NGFI design should offer the maximum possible support for capacity maximizing coordinated algorithms (e.g., joint scheduling, joint reception and joint transmission).

2.2.4 Decoupling of interface traffic from number of antennas at RRU

This means that processing involving direct contact with the antenna should be carried out at the remote head. This will maximize adaptability in the future, when large antenna arrays are introduced, and will prevent explosion in demand for NGFI bandwidth as the number of antennas supported at the RRU increases.
2.2.5 Neutrality with respect to air interface technology

The NGFI should be capable of supporting not just 4G LTE, but also future 5G technologies, meaning the interface between the RCC and RRS must satisfy principles 2.2.1–2.2.5 for 5G air interface technology.

Considering the data volumes involved, we recommend Ethernet transmission for fronthaul. This will speed up rollout by making use of existing Ethernet networks and will also offer the statistical multiplexing and flexible routing benefits of packet transmission, which will raise transmission efficiency and make the network more flexible.

2.2.6 Optimization of RRS-RCC connections

RRS means the ability to transfer baseband processing from one RCC to another RCC, along with RRS functions; at the same time, an RRS can only connect to one RCC at a time. When traffic volumes are high, RRS connections will be dynamically adjusted to balance payload; when traffic volumes are low, processing can be centralized to reduce energy waste and allow better statistical multiplexing of resources within the RCC.

Flexible RRS connections will increase network reliability. In the event of a problem in any given RCC, its RRSs can have their connections distributed to other RCCs.

2.3 NGFI logical layers

The NGFI has three logical layers: the data layer, data adaptation layer, and physical carrier layer. The data layer contains user data, control data, synchronization data and control data associated with all radio technologies. As radio technologies advance, the bandwidth and functional requirements of the user data and control data will change, depending on the functional division at the base station and the type of radio access network (4G/5G). The adaptation layer adapts the radio data to the transmission network: its function is to ensure that the transmission features of this data remain well-matched to the features of the lower-level transmission network. The physical carrier layer could be any one of the current main access networks: packet transport network (PTN), passive optical network (PON), wavelength division multiplexing (WDM), etc.
2.4 Advantages of NGFI

NGFI offers network operators significant advantages over the old CPRI interface in several areas.

- NGFI raises transmission efficiency and reduces cost pressure on the fronthaul network by taking advantage of the averaging of mobile traffic across the network through statistical multiplexing.

- NGFI greatly reduces the bandwidth required for RCC-RRS transmission. Given the new architecture, which physically separates RCC and RRS equipment, this enables the use of multiple antennas, allowing deployment of fewer RCC stations and coordination of functions across the radio network. This will allow the network to adapt to the needs of future network architecture development.

- NGFI uses Ethernet transmission, thereby making maximal use of existing network architecture for roll out and maintenance. Ethernet networks are flexible and reliable, and the operation and maintenance interfaces are straightforward. They also allow easy statistical multiplexing, which will help maintain high functionality. The flexible routing of an Ethernet network also allows network operators to share network fronthaul resources, which can reduce infrastructure costs.

- Allows easier sharing of fronthaul and backhaul network resources.

- Allows network virtualization for better support of RAN sharing and easier response to demand for customized services.

2.5 NGFI applications

2.5.1 General service scenarios

NGFI can be applied in general use scenarios. Base stations within a general access area connect to the RCC and remote RRSs through existing fiber loops for a centralized BBU architecture. The existing fiber
network carries the NGFI data. Each loop connects six to eight metrocells, with each antenna installation generally being S2/2/2 (i.e. three cells, two carrier waves per cell). As traffic grows in the future, metrocells could grow to S3/3/3 configuration. The physical locations of the RCC processing point and remote RRS is generally no farther than 20 km.

2.5.2 Indoor systems

In indoor systems, NGFI data is carried between the RCC and remote RRSs through the building’s ample cable resources. The number of RRSs depends on the scenario; it could be 10, a few dozen, or even over 100.

2.5.3 Metrocell-based, terminal-located processing

In this scenario, to satisfy traffic demands, RCC is placed at the metrocells in high-demand areas, with the RRS formed from remote radio heads. This guarantees high capacity, and the two are directly connected with fiber or through existing access network cables. To save cable, RRSs can be connected in a cascade. When metrocells are set up in the standard S3/3/3 configuration, remote heads generally have two antennas with 360-degree coverage. The ratio of metrocells to remote heads is usually between 1:3 and 1:6, but where traffic is high, one metrocell may have up to nine remote heads, or even more. The distance between remote heads and metrocells is generally a few kilometers.

5G will require denser deployment of remote heads to provide its broad coverage and high speeds and will also demand interoperability between heterogeneous networks to prevent interference when shifting from one network to another (e.g., 5G/4G, 4G/Wi-Fi, 5G/4G/Wi-Fi). Control of remote heads must be centralized at metrocells and provide data aggregation. This architecture will allow smooth evolution from 4G to 5G. NGFI networks allow aggregation of remote head data at metrocells, with dynamic configuration of the remote head transmission network.
3 POTENTIAL NGFI DESIGNS

This section analyzes potential NGFI designs. It does not represent an exhaustive list of possible forms, and we look forward to more input from the industry, so that we can choose the optimum model. The current preliminary analysis only addresses current LTE technology. We offer only an initial qualitative analysis of some possible future demands on networks (e.g., from massive MIMO, short packet). This analysis will gradually be extended to cover all possible arrangements and determine their advantages and disadvantages and the demands they place on NGFI performance.

3.1 Possible divisions of the RCC-RRS interface

The figure above shows possible division schemes for the RCC-RRS interface in LTE, along with the demands that the various divisions place on fronthaul bandwidth and on the radio side. Baseband processing in both uplink and downlink can be divided into user-level processing (related to traffic levels) and cell-level
processing (unrelated to traffic levels). The green sections of the figure are traffic-dependent, user-level processing modules; yellow sections are traffic-independent, cell-level processing modules. The blue section, channel estimation and equalization, is also user-level processing, but the complexity of channel estimation and equalization is also correlated with the number of receiving antennas.

To assess the bandwidth demands that different divisions of the RCC-RRS interface will place on the fronthaul, we make the following assumptions:[5]

1) 20M LTE carrier waves
2) 2 terminals
3) 8 antennas
4) Downlink spectrum efficiency of 2 b/s/Hz, uplink efficiency of 1.8 b/s/Hz
5) Downlink maximum modulation level at full payload is 64 QAM; uplink is 16 QAM
6) Maximum no. of users: 100

Note: The bandwidth calculation below is for cell bandwidth per sector per carrier wave. It does not include synchronization data or Ethernet headers. The additional load created by Ethernet headers will vary depending on the length of the Ethernet packets. Here, we provide only a simplified analysis of each scheme; uplink and downlink schemes do not have to have the same divisions. Also, different schemes could be applied to each separate information channel to improve efficiency. For example, PSS, SSS, RS and PBCH signals could be configured to be produced at the RAU to reduce demand for bandwidth.

### 3.1.1 Scheme 1: Internal division of layer 2

Internal division of layer 2 (L2) is a scheme designed for the needs of LTE-A, pre-5G and 5G evolution. It also minimizes the demands on the transmission network and is easy to implement. This scheme meets the following criteria:

1) Network architecture allows millisecond-level coordination across multiple cells and is flexible enough to support the complex demands of future scheduling algorithms.
2) L2 scheduling is extendable based on the number of users and connections, allowing it to flexibly adapt to variations in capacity of base stations and sizes of networks; it also adapts to the needs of super-dense cells and heterogeneous networks.
3) The complexity of the processing assigned to the RCC function is correlated linearly with traffic volume but not with number of carrier waves; the complexity of the processing assigned to the remote RSS function is not correlated with traffic volume.
4) Easily adaptable to current Ethernet networks (delay, jitter and bandwidth). Supports transmission latencies in the 100 µs to 10 ms range.

5) Compatible with the physical layers of multiple generations of radio technologies, and can be cooperative with them.

6) Supports traffic-oriented scheduling.

The High MAC-Low MAC division scheme is motivated by two considerations. First, placing the functions with stringent delay requirements (like HARQ) in the RRS end while keeping the other functions on the BBU side reduces the delay pressure on the NGFI interface. Second, as networks evolve, NGFI must consider the need to support cooperation between multiple carrier waves and increasing numbers of technologies. The MAC function can be divided into multi-carrier MAC and single-carrier MAC. The multi-carrier MAC function is the “brain” of multiple carrier waves: it scans and processes data and decides whether it needs to coordinate multiple carriers and how to coordinate them. Single-carrier MAC is the MAC function within a single carrier wave, e.g., mapping/demapping of a logic channel to a transmission module, data multiplexing/demultiplexing and HARQ. Dividing the functions within the MAC level conforms to the principle of allowing interface bandwidth to dynamically vary with traffic load (number of carrier waves, number of coordinated users, etc.). The information exchanged between the multi-carrier MAC and single-carrier MAC functions is primarily in the cell and user channels. Coordinated carrier waves form a first-level cooperative cluster; multiple clusters form a second-level cooperative cluster, etc., forming a tree-branch system of cooperation. The data/information volumes required at each level are different, and they have different interaction periodicity. To estimate bandwidth requirements for division within the MAC function, we make the following assumptions:

1) 5 cooperating carrier waves

2) Maximum number of simultaneously coordinated users across 5 carrier waves: 300

Based on current LTE networks, the MAC division scheme requires a similar level of bandwidth to the scheme dividing the functions between the MAC/PHY levels, i.e. about 150 Mb/s downlink and 75 Mb/s uplink. From experience, uplink interaction data is mainly channel measurement information; downlink data is mainly downlink control information. Therefore, each coordinated user sends and receives interaction data about 10 bits in length. Across 300 users on five carrier waves, this amounts to about 24 Mb/s. Because of variation in instantiations and overheads, we assume 10–20% of the maximum bandwidth as an overhead. For the division scheme between the MAC/PHY layers, the total bandwidths required for downlink and uplink carrier waves will be as follows:

1) Downlink: 180 Mb/s
2) Uplink: 109 Mb/s

Both the HARQ and single-carrier MAC functions are placed in the RRU. This means that, in this scheme, the NGFI is not constrained by the LTE demand of a maximum response time of 4 ms for HARQ. The delay requirements between multi-carrier MAC and single-carrier MAC depends on the scenario. For example, where there is frequent shifting of channels, transmission latencies must be short. Our initial estimate is that, in the MAC-internal division scheme, NGFI delay will have to be constrained at the level of 100s of µs. When the MAC functions with the tightest delay constraints are placed on the RRU side, the maximum delay of the NGFI can be relaxed to 3–5 ms without any significant impact on radio functionality. RLC also imposes some time constraints, and MAC data may also spike. Therefore, the maximum bandwidth required may far exceed the average. For example, when transmission delay is 100 µs, the maximum instantaneous bandwidth demand will spike to 180 Mb/s/100 µs=1.8 Gbps. If the downlink RLC layer is placed at the remote side, delay demands can be relaxed a little further. But, if it becomes necessary to maintain or upgrade the system by optimizing single-carrier MAC or physical layer performance, or aggregating carrier waves, the chips and software at the RRU will also require additional capacity and upgrading. Shifting the RLC layer to the remote side would therefore greatly increase the difficulty of maintenance. Considering the possibility of future high-density technologies (e.g. massive MIMO), the MAC-internal division scheme offers low demands on fronthaul transmission bandwidths, reducing demands on the fronthaul network, with associated lower costs. This analysis shows that introducing multi-carrier MAC will greatly improve carrier wave cooperation, boosting the gains from cooperation. The MAC-internal division scheme would also be helpful in introducing coordinated scheduling (CS) in the RCC, cooperation technologies above the physical layer, and C/U separation.

### 3.1.2 Scheme 2: Division between MAC/PHY

This scheme places the division between the MAC and PHY layers. This allows simple and clear division of functions and means that the NGFI will conform to the principle of bandwidth varying with traffic. If all functions above the MAC level are centralized on the server, the powerful performance of the server will allow centralized scheduling and evolution toward 5G architecture. At the same time, the PHY layer will be released from its ties to the higher layers and can evolve independently in terms of both hardware and software.

Division between the MAC/PHY levels has the following advantages:

1) If all functions above the MAC layer are placed at the server, the server's processing power allows highly centralized processing and scheduling, which will help to build on the current demand for LTE-A. For example, carrier aggregation (CA), dual connectivity, coordinated multipoint processing (CoMP) and LTE-U.
2) Supports introduction of general processing systems: as virtual systems develop further, RCC functions will become much more flexibly expandable.

3) Supports shifting of RCC functions to the cloud for sharing of processing capacity and resources and reduced waste.

4) The centralization of the MAC layer will allow for multiple cells to be coordinated at the ms level, which will help enable the future introduction of complex scheduling algorithms and be a useful condition for the evolution of 5G architecture.

5) Physical layer hardware will not need to be bundled with higher layer applications and can evolve independently.

Peak bandwidth for a 20-MHz LTE downlink carrier wave at the MAC and PHY levels is 150 Mb/s; peak uplink bandwidth is 75 Mb/s. Given assumption (4) above, average bandwidth for a downlink wave would be 40 Mb/s and 36 Mb/s for uplink. This MAC/PHY division scheme also includes excess payload, which is mainly scheduling and configuration data, such as MCS, resource block allocations and antenna configuration.

To assess the data requirements of scheduling and configuration, we make the following assumptions:

1) Data overhead for indicating user uplink/downlink MCS is 1 bit/user/ms.

2) Overhead for indicating user uplink/downlink resource block allocations is 1 bit/user/ms.

3) Overhead for antenna configuration is 2 bits/user/ms.

4) If the beamforming bit width is 8 bits, then the beamforming overhead will be 2 bits/RB/terminal/antenna.

5) Scheduling and configuration packets will require an additional overhead of 1 bit/user/ms.

Given assumption (6) above, our initial estimate of the downlink bandwidth required for scheduling data is \[(1+1+2+0.5) \times 100 \times 2 \times 1000 = 29.2\text{Mb/s};\] for the uplink, it is \[(1+1+2+0.5) \times 8 \times 100 \times 1000 = 3.6\text{Mb/s}.\]

For the MAC/PHY division scheme, the total bandwidth required for each downlink carrier wave is therefore:

1) Downlink bandwidth: 69.2 Mb/s

2) Uplink bandwidth: 39.6 Mb/s

Due to different vendors adopting different implementation methods and encapsulation on different network layers has varying bandwidth requirements, an additional bandwidth of between 30% - 50% of the service bandwidth is required. As a result, the peak downlink and uplink bandwidth per carrier are:

1) Downlink bandwidth: 225 Mb/s
2) Uplink bandwidth: 112.5 Mb/s

LTE’s maximum HARQ response time is limited to 4 ms. This requires low NGFI transmission delay between RCC and PHY in the MAC/PHY division solution. Research data shows that, when the processing delay of functions remains unchanged but the round-trip transmission delay between the overlaying MAC and PHY is greater than 1 ms, the peak rate per user will be affected significantly. If the round-trip transmission delay between the overlaying MAC and PHY is less than 3 ms, the average cell throughput will not be affected significantly. In addition, burst data transmission may occur at the MAC layer. Therefore, instantaneous bandwidth much greater than the data bandwidth may be required to comply with the delay requirement. For example, if the unidirectional transmission delay is 100 us, the actual link bandwidth should be 225 Mb/s/100 us = 2.25 Gbps. For future-oriented ultra-large-capacity and ultra-dense transmission technology (such as Massive MIMO), the MAC/PHY division solution helps to greatly reduce the requirements for front-end transmission bandwidth and front-end transmission resources, resulting in significantly lower reduction of the front-end transmission costs. The MAC/PHY division solution better facilitates cooperation in RCC layers other than PHY. The solution mainly involves CS of CoMP, various enhanced technologies available above the PHY layer, and C/U separation. Since physical layer functions are implemented by the remote RRU, chips or software that implements the functions must be upgraded in the remote RRU or added to the remote RRU for system maintenance and capacity upgrades such as physical layer performance optimization or carrier aggregation. This significantly increases the difficulty of upgrading and maintenance.

3.1.3 Solution 3——Bit-level/Symbol-level Division Solution

The bit-level/symbol-level division solution allows interface bandwidth to vary dynamically with service load. Based on the bandwidth and modulation levels specified in the preceding 1st and 5th basic assumptions, if the common control channel uses one OFDM symbol in the full service load condition, the downlink data bandwidth between the bit-level processing unit and symbol-level processing unit of 20 MHz LTE carriers is about \((1200 \times 6 \times 13 + 1200 \times 2 \times 1) \times 1000 = 96\) Mb/s; if the soft bit information bit width is 8 bits for uplink transmission, the uplink data bandwidth is \((1200 \times 4 \times 8 \times 12) \times 1000 = 461\) Mb/s. According to the assessment on scheduling and configuration data bandwidth of the MAC/PHY division solution, the total uplink bandwidth and downlink bandwidth of the bit-level/symbol-level division solution are:

1) Downlink bandwidth: 125.2 Mb/s
2) Uplink bandwidth: 464.6 Mb/s

LTE’s maximum HARQ response time is limited to 4 ms. This requires a low NGFI transmission delay between the BBU and RRU in the bit-level/symbol-level division solution. If the delay reaches or exceeds 1,000 us, the LTE air interface is unable to meet performance requirements. If physical layer functions other than bit-level functions must be upgraded or enhanced, physical layer processing chips and software must be upgraded or updated on the remote RRU. This slightly increases the difficulty of upgrading and maintenance.
For future-oriented ultra-large-capacity and ultra-dense transmission technology (such as Massive MIMO), the traditional CPRI interface requires many transmission resources. The bit-level/symbol-level division solution helps to greatly reduce the requirements for front-end transmission bandwidth and front-end transmission resources, resulting in lower front-end transmission costs. In RCC, the bit-level/symbol-level division solution not only enables the implementation of the cooperation technology described in the MAC/PHY division solution, but also facilitates the implementation of the soft information combination algorithm proposed based on joint reception (JR) and non-coherent joint transmission (JT).

3.1.4 Solution 4——Symbol-level/Sample-level Division Solution

Symbol-level/Sample-level allows interface bandwidth to vary dynamically with service load. Based on the number of ports specified in the preceding 2nd basic assumption, if the bit width of the downlink sampling point is 7 bits under the condition of a full service load, the downlink data bandwidth corresponding to 20 MHz LTE carrier port 4 is about \((1200 \times 7 \times 2 \times 14) \times 2 \times 1000 = 470.4 \text{ Mb/s}\); if the bit width of the uplink sampling point is 10 bits for uplink transmission, the uplink data bandwidth calculated based on the preceding 3rd basic assumption is \((1200 \times 10 \times 2 \times 14) \times 8 \times 1000 = 2,688 \text{ Mb/s}\). The additional load of the symbol-level/sample-level division solution includes downlink and uplink RB allocation information, downlink antenna configuration, downlink beam-forming factor, and additional load for scheduling and configuration packet assembly. According to the assessment on scheduling and configuration data bandwidth of the MAC/PHY division solution, the downlink bandwidth of the symbol-level/sample-level division solution for the additional load is \([(1 + 0.5) \times 100 + 2 \times 100 \times 2 \times 8] \times 8 \times 1000 = 27.6 \text{ Mb/s}\) and the uplink bandwidth of the symbol-level/sample-level division solution for the additional load is \((1 + 0.5) \times 8 \times 100 \times 1000 = 1.2 \text{ Mb/s}\). Therefore, the total downlink bandwidth and uplink bandwidth of the symbol-level/sample-level division solution are:

1) Downlink bandwidth: 498 Mb/s
2) Uplink bandwidth: 2,689.2 Mb/s

The uplink data bandwidth and downlink data bandwidth may vary according to different implementation methods adopted by different vendors (for example, they may use different bit widths for downlink and uplink sampling points). If both the bit width of uplink and downlink sampling points are 16 bits and the downlink transfers antenna data instead of port data, the uplink and downlink service data bandwidth is \((1,200 \times 16 \times 2 \times 14) \times 8 \times 1,000 = 4,300.8 \text{ Mb/s}\) each. The total uplink and bandwidth are 4,730.9 Mbps each, including an additional 10% bandwidth for the additional load.

LTE’s maximum HARQ response time is limited to 4 ms. This requires low NGFI transmission delay between the BBU and RRU in the symbol-level/sample-level division solution. If delay reaches or exceeds 1,000 us, the LTE air interface is unable to meet performance requirements. In the current LTE OFDM solution, sample-level processing remains almost unchanged even though functions of the physical level are implemented in the remote RRU. Therefore, the difficulty of upgrading and maintenance does not significantly
increase. However, if the number of antennas is increased significantly, for example, it is increased to 64, 128, or more, the number of antennas will be greater than the number of antenna ports defined in 3GPP R13. If there are 8 antenna ports and antenna data mapping is implemented using the time domain form factor, the transmission bandwidth requirement is the same as that of 8 antennas. If there are 16, 32, or 64 antenna ports or antenna data mapping is implemented without using the time domain form factor, the front-end transmission bandwidth requirement will increase significantly. In RCC, the symbol-level/sample-level division solution not only enables the implementation of the technology mentioned in the bit-level/symbol-level division solution description, but also facilitates the implementation of the symbol-level JR.

3.1.5 Solution 5——Baseband/RF Division Solution

The baseband/RF division solution is an interface solution for the BBU and RRU of existing devices. According to the solution, interface bandwidth is unrelated to service load. The bandwidth is fixed at 30.72 Mbps × 32 × (10/8) × 8 = 9,830.4 Mbps. The total downlink and uplink bandwidth of the solution are:

1) Downlink bandwidth: 9,830.4 Mb/s

2) Uplink bandwidth: 9,830.4 Mb/s

LTE’s maximum one-way delay is limited to 4 ms. This requires low NGFI transmission delay between the BBU and RRU in the baseband/RF division solution. If delay reaches or exceeds 1,000 us, the LTE air interface is unable to meet performance requirements. RRU only implements RF-related functions, and therefore upgrading and maintenance are not difficult. For future-oriented ultra-large-capacity and ultra-dense transmission technology (such as Massive MIMO), the baseband/RF division solution requires significant front-end transmission bandwidth and many front-end transmission resources, resulting in high front-end transmission costs. Although the baseband/RF division solution supports all of the cooperation technologies mentioned above, it is very difficult to reduce delay to less than 1,000 us after CPRI data is encapsulated into IP packets.

3.1.6 Interface Division Solutions Comparison and Analysis

The following table is created based on bandwidth requirements analysis of interface division solutions 1 to 5 mentioned above. In the table, Ratio indicates the ratio of front-end transmission bandwidth to backhaul bandwidth; the bandwidth of interfaces 1, 2, 3, and 4 is the maximum or peak bandwidth, and the bandwidth of interface 5 is fixed.
Table 3-1: Maximum Interface Bandwidth

<table>
<thead>
<tr>
<th></th>
<th>Interface 1</th>
<th>Interface 2</th>
<th>Interface 3</th>
<th>Interface 4</th>
<th>Interface 5</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bandwidth</td>
<td>174 Mb/s</td>
<td>179.2 Mb/s</td>
<td>125.2 Mb/s</td>
<td>498 Mb/s</td>
<td>9,830.4 MB/s</td>
</tr>
<tr>
<td>Ratio</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>3</td>
<td>66</td>
</tr>
<tr>
<td>Downlink</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Uplink</td>
<td>99 Mb/s</td>
<td>78.6 Mb/s</td>
<td>464.6 Mb/s</td>
<td>2,689.2 Mb/s</td>
<td>9,830.4 MB/s</td>
</tr>
<tr>
<td>Ratio</td>
<td>1</td>
<td>100</td>
<td>6</td>
<td>36</td>
<td>131</td>
</tr>
</tbody>
</table>

As described above, the use of multi-carrier MAC greatly improves inter-carrier cooperation and helps obtain the most cooperative gain. Due to the existing CoMP technology, different interface division solutions between BBU and RRU have different requirements for front-end transmission bandwidth and support different cooperation algorithm levels, as shown in the following table:

Table 3-2: Interface Delay

<table>
<thead>
<tr>
<th></th>
<th>Interface 1</th>
<th>Interface 2</th>
<th>Interface 3</th>
<th>Interface 4</th>
<th>Interface 5</th>
</tr>
</thead>
<tbody>
<tr>
<td>Delay</td>
<td>Less than 100 ms</td>
<td>Less than 1 ms</td>
<td>Less than 1 ms</td>
<td>Less than 1 ms</td>
<td>Less than 1 ms</td>
</tr>
<tr>
<td>Ratio</td>
<td>1</td>
<td>100</td>
<td>100</td>
<td>100</td>
<td>100</td>
</tr>
</tbody>
</table>

Table 3-3: Cooperation Algorithm Levels Supported by the Interfaces

<table>
<thead>
<tr>
<th></th>
<th>Interface 1</th>
<th>Interface 2</th>
<th>Interface 3</th>
<th>Interface 4</th>
<th>Interface 5</th>
</tr>
</thead>
<tbody>
<tr>
<td>Downlink</td>
<td>CS/CB</td>
<td>CS/CB</td>
<td>CS/CB</td>
<td>CS/CB</td>
<td>CS/CB</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Non-coherent JT</td>
<td>Non-coherent JT</td>
<td>Non-coherent JT</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Coherent JT</td>
<td>Coherent JT</td>
<td>Coherent JT</td>
</tr>
<tr>
<td>Uplink</td>
<td>CS/CB</td>
<td>CS/CB</td>
<td>CS/CB</td>
<td>CS/CB</td>
<td>CS/CB</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Soft information combination-JR</td>
<td>Soft information combination-JR</td>
<td>Soft information combination-JR</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>MMSE-JR</td>
<td>MMSE-JR</td>
<td>MMSE-JR</td>
</tr>
</tbody>
</table>
Table 3-4: Other Features of the Interfaces

<table>
<thead>
<tr>
<th></th>
<th>Interface 1 MAC</th>
<th>Interface 2 MAC-PHY</th>
<th>Interface 3 Bit Level</th>
<th>Interface 4 Symbol Level</th>
<th>Interface 5 I/Q</th>
</tr>
</thead>
<tbody>
<tr>
<td>RAU complexity</td>
<td>High</td>
<td>High</td>
<td>High</td>
<td>Low</td>
<td>Lowest</td>
</tr>
<tr>
<td>Interface complexity</td>
<td>Low</td>
<td>High</td>
<td>Medium</td>
<td>Low</td>
<td>Low</td>
</tr>
<tr>
<td>Interactive receiver</td>
<td>Supported in RAU</td>
<td>Supported in RAU</td>
<td>Hard-decoding interaction not supported</td>
<td>Supported in RCC</td>
<td>Supported in RCC</td>
</tr>
<tr>
<td>Pooling gain</td>
<td>Small</td>
<td>Relatively small</td>
<td>Relatively small</td>
<td>Large</td>
<td>Large</td>
</tr>
<tr>
<td>Upgrade and</td>
<td>High</td>
<td>High</td>
<td>High</td>
<td>Low</td>
<td>Low</td>
</tr>
<tr>
<td>maintenance difficulty</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Different interface division solutions have different features and must match the underlying transport bearer technology to form next-generation wireless network main device interfaces to facilitate future evolution of wireless access networks.

3.1.7 Potential Requirements for Data Exchange Between RRSs Analysis

After function restructuring, BBU and RRU are renamed RCC and RRS. According to the RRS function definition, RRSs can exchange data to address requirements for cooperation and wireless functions. However, the data exchange is not always necessary. For example, RRS in division solution 4 implements simple functions and RCC meets most requirements for cooperation and wireless functions. Therefore, RRSs do not need to exchange data. In division solution 1, if cooperation between physical layers is implemented, RRSs must exchange data. The performance requirements (such as delay and bandwidth requirements) of data exchanges between RRSs depends on the BBU/RRU function restructuring solution.

A solution of interface division between RCC and RRS can be regarded as a hard division solution, where RRS data is transferred to RCC for aggregation and processing. A solution of interface division between RRS and RRS can be regarded as a soft division solution, which allows flexible data transmission between RRS and RRS and allows data exchanges between peer functional layers of RRSs. If cooperation function implementation is restricted by RRS/RCC function division based on technologies such as JT, MMSE-IRC, and UL soft information combination, the cooperation function can be implemented through data exchanges between RRSs.

Therefore, according to the overall requirements of a system for physical transmission devices, front-end transmission devices must support data exchanges between RCC and RRS as well as data exchanges between RRSs. To address these requirements, higher capability transmission devices must be designed.
3.2 Transmission and Processing Delay Allocation Solution Analysis

According to the LTE protocol's HARQ process requirement, if the uplink data transmission of a terminal air interface reaches the time (unit: ms) of the T1 sub-frame on an RRU base station, the base station must notify the terminal of the translation result of the corresponding uplink timeslot at the time of the T1+4 sub-frame. Depending on the notification, the terminal resends previous data packets or sends new data packets. The period between the time of the T1 sub-frame and the time of the T1+4 sub-frame is 5 milliseconds, of which 2 milliseconds are used by the air interface to perform uplink and downlink data transmission. Only 3 milliseconds are left for the base station to process data. The 3 milliseconds include:

- Time of data transmission between RRU and BBU $t_{\text{trans}}$ (Both directions in the round-trip transmission have the same delay.)
- Time of processing in BBU $t_{\text{process}}$

3.2.1 Delay Estimation of the BBU/RRU Architecture Using the CPRI Interface

The CPRI interface supports a maximum transmission distance of 20 KM. According to the speed of light in an optical fiber, if BBU and RRU are connected using the CPRI interface, the data transmission time over optical fiber to cover the distance is $t_{\text{trans}} = 100$ us. Therefore, after round-trip data transmission delay is deducted, the total processing time available to BBU is:

$$t_{\text{process}} = t_{\text{total}} - 2 \times t_{\text{trans}} = 2.8\text{ms}$$

If each baseband processing board handles six 8-antenna 20 MHz carriers on average and each baseband board is equipped with two core processing chips, each chip handles three 8-antenna 20 MHz carriers. If each chip has $N$ cores, the processing time is 2.8 ms, and 3 sub-frames of 3 carriers must be processed every millisecond, the processing time of each sub-frame is $2.8/3 = 0.9$ ms. According to the initial estimation, the processing capacity of $N/3$ cores of a chip is required for processing each carrier every millisecond. The processing time of each carrier is $2.8/3 = 0.9$ ms, or 900 us. This time includes the uplink data processing time of the physical layer, the downlink data processing time of the physical layer, and the processing time of the MAC layer.

3.2.2 Delay Estimation of the RCC/RRS Architecture Using NGFI

If NGFI is used, recreated division points are located between HARQs. Because of additional switch packet exchange delay, more time is required for data transmission. In the worst-case transmission scenario, the time of unidirectional data transmission is $t_{\text{trans}} = 500$ us. In this case, the total processing time available to BBU is:

$$t_{\text{process}} = t_{\text{total}} - 2 \times t_{\text{trans}} = 2\text{ms}$$

Based on the original processing mode of the baseband software and the processing capacities of current baseband chips (absolute processing time of a single carrier: 0.9 ms), a current baseband processing board
can handle only four 8-antenna 20 MHz carriers. If the processing mode of the baseband software is optimized, the processing time can be reduced by adding concurrent processing tasks without adding processing resources.

In the baseband processing flow, the steps that are most time consuming and cannot be performed in a parallel manner require the most processing time. The locations of the processing sub-modules in these steps do not affect the total delay.

In conclusion, if less time is available for data transmission, the switch delay must be lowered, which results in higher transmission device costs. If less time is available for baseband processing, the main wireless devices must have higher processing power. The primary challenge is determining how to balance the time allowance between data transmission devices and baseband processing devices without changing the total time allowed. A certain degree of cost increase is acceptable if the additional benefits from packet switching are taken into consideration. Therefore, creating division points between HARQs is not entirely unacceptable.

According to the regulations on centralized purchasing of transmission devices, the data forwarding time of a hop device must not exceed 50 us. Therefore, the maximum data forwarding time of 6 hop devices is 300 us. Currently, the data forwarding time of a switch chip in a transmission device can be as short as about 1 us. The long data forwarding time of existing transmission devices is caused by various system design factors. In addition, external auxiliary chips (for complex QoS setup and so on) increase the delay. Currently, some switch chip companies plan to develop switch chips with delay less than 1 us. Therefore, if network switch devices for front-end transmission are designed based on an optimized switch chip, the number of auxiliary chips is reduced, and when the switch chip is configured properly, the data forwarding time of a hop device may be reduced to 20 us or even less than 10 us.

### 3.3 Convergence Ratio of Statistical Multiplexing Analysis

A convergence ratio of statistical multiplexing is estimated based on a reference service model developed according to live network data provided by Beijing Mobile. The total load of multiple sites in different periods will be analyzed using a smaller time unit (such as 15 minutes). More live network data will need to be analyzed in order to optimize the reference service model.

Convergence is a process where $N$ is mapped to $M$. If the total peak bandwidth for front-end transmission by $X$ base stations is $N$, all of the base stations work in compliance with the reference service model, and the front-end transmission system with $M$ bandwidth meets the front-end transmission requirements of the $X$ base stations under a specified QoS agreement, the convergence ratio of statistical multiplexing is $M:N$.

### 3.3.1 Analysis of Existing Network Data

Beijing Mobile provided seven consecutive days of load-monitoring data for six sites near Tianning Temple, four of which were outdoor macro base stations, including 11 TDD LTE carriers, while the other two were
indoor distribution systems, including 25 carriers. The time interval for data monitoring was 15 minutes, i.e. carrier load status was queried every 15 minutes. The data monitoring area, which is located near the China Mobile Research Institute, contains a large number of 4G end users and can be regarded as a typical CBD traffic area that meets the requirements of a typical TDD LTE traffic scenario.

The six sites were respectively named Site 1 to Site 6, traffic volume was measured as a percentage and the value range was [0,100]. Backhaul bandwidth was measured in megabits per second (Mbps). The peak or trough value subitem time denotes the absolute time of the peak or trough value each day from 0 to 24 hours, the mean value subitem time denotes the continuous length of time that traffic volume is between [mean traffic volume -1%, mean traffic volume +1%], given in hours (h). The monitored traffic data for the six sites is shown below.

<table>
<thead>
<tr>
<th>Site</th>
<th>Peak Value</th>
<th>Trough Value</th>
<th>Mean</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Downlink</td>
<td>Uplink</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Air Interface</td>
<td>Backhaul</td>
<td>Air Interface</td>
</tr>
<tr>
<td>1</td>
<td>54.22</td>
<td>75.4</td>
<td>0.78</td>
</tr>
<tr>
<td></td>
<td>17.86</td>
<td>2.38</td>
<td>3.17</td>
</tr>
<tr>
<td>2</td>
<td>83.54</td>
<td>175</td>
<td>0.72</td>
</tr>
<tr>
<td></td>
<td>20.19</td>
<td>12.5</td>
<td>3.02</td>
</tr>
<tr>
<td>3</td>
<td>34.28</td>
<td>80.2</td>
<td>0.77</td>
</tr>
<tr>
<td></td>
<td>34.21</td>
<td>11.7</td>
<td>3.14</td>
</tr>
<tr>
<td>4</td>
<td>13.26</td>
<td>25</td>
<td>0.73</td>
</tr>
<tr>
<td></td>
<td>19.57</td>
<td>2.52</td>
<td>3.01</td>
</tr>
<tr>
<td>5</td>
<td>18.98</td>
<td>93.5</td>
<td>0.69</td>
</tr>
<tr>
<td></td>
<td>34.26</td>
<td>18.8</td>
<td>3</td>
</tr>
<tr>
<td>6</td>
<td>20.38</td>
<td>144</td>
<td>0.7</td>
</tr>
<tr>
<td></td>
<td>47.06</td>
<td>34.2</td>
<td>3</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Station</th>
<th>Peak Value</th>
<th>Trough Value</th>
<th>Mean</th>
</tr>
</thead>
<tbody>
<tr>
<td>Site 1</td>
<td>Downlink</td>
<td>11:45–12:00</td>
<td>1:15–6:15</td>
</tr>
<tr>
<td></td>
<td>Uplink</td>
<td>11:45–12:00</td>
<td>0:45–6:15</td>
</tr>
<tr>
<td>Site 2</td>
<td>Downlink</td>
<td>15:30–16:00</td>
<td>0:30–6:00</td>
</tr>
<tr>
<td></td>
<td>Uplink</td>
<td>15:00–15:15</td>
<td>1:30–6:00</td>
</tr>
<tr>
<td>Site 3</td>
<td>Downlink</td>
<td>11:30–11:45</td>
<td>0:00–5:15</td>
</tr>
<tr>
<td></td>
<td>Uplink</td>
<td>21:30–21:45</td>
<td>0:00–6:15</td>
</tr>
<tr>
<td>Site 4</td>
<td>Downlink</td>
<td>19:00–19:30</td>
<td>3:00–5:00</td>
</tr>
<tr>
<td></td>
<td>Uplink</td>
<td>2:00–2:15</td>
<td>3:00–6:00</td>
</tr>
<tr>
<td>Site 5</td>
<td>Downlink</td>
<td>9:30–9:45</td>
<td>20:15–8:00</td>
</tr>
<tr>
<td></td>
<td>Uplink</td>
<td>17:15–17:30</td>
<td>20:15–8:00</td>
</tr>
<tr>
<td>Site 6</td>
<td>Downlink</td>
<td>13:30–13:45</td>
<td>21:00–8:15</td>
</tr>
<tr>
<td></td>
<td>Uplink</td>
<td>14:00–14:15</td>
<td>21:00–8:15</td>
</tr>
</tbody>
</table>
Fig. 3-3: Changes in Daily Downlink Traffic Load

Fig. 3-4: Mean Daily Downlink Traffic Load
The following characteristics can be deduced from the above statistics:

1) Peak traffic values are not high and have a fairly short duration, lasting no more than 30 minutes.
2) The probability of peak values occurring simultaneously at multiple sites is almost zero.
3) Trough traffic values are very low and have longer duration, lasting more than two hours.
4) Trough values occur simultaneously at multiple sites, and the overlap time is quite long.
5) Mean traffic volume is quite low, and most of the time traffic volume is distributed close to the mean traffic volume.
6) Office buildings and other office areas exhibit a very significant tidal effect, with 0 load for at least half the time every day.
7) Uplink traffic volume is lower than downlink traffic volume; in particular, uplink backhaul bandwidth is 1/10 downlink backhaul bandwidth.

3.3.2 Reference Traffic Model and Convergence Ratio Analysis

Based on the above statistics, and allowing room for future increase in traffic volume, the following traffic model was established as a preliminary reference.
<table>
<thead>
<tr>
<th>Parameter</th>
<th>Idle Time Load</th>
<th>Medium Load</th>
<th>Busy Time Load</th>
</tr>
</thead>
<tbody>
<tr>
<td>20M/8 antennas/TD-LTE</td>
<td>There is only control channel data and a very small amount of shared channel data; RB occupancy rate is less than 10%</td>
<td>There is control channel data and a moderate level of shared channel data; RB occupancy rate is greater than 10% and less than 60%</td>
<td>There is control channel data and quite a large amount of shared channel data; RB occupancy rate is greater than 60%</td>
</tr>
<tr>
<td>Length of reference traffic load</td>
<td>8 hours</td>
<td>12 hours</td>
<td>4 hours</td>
</tr>
</tbody>
</table>

Therefore, based on the above reference traffic model, we can obtain data with which to calculate the multiplexing convergence ratio as 
\[
\frac{10\% \times 8 + (10\% + 60\%) / 2 \times 12 + (60\% + 100\%) / 2 \times 4}{24} = 34\% ,
\]
i.e. the data convergence ratio is approximately 1:3.

### 3.4 Summary of Schemes

Based on an analysis of the above potential schemes, NGFI is a compromise solution that takes into account front-end transmission bandwidth, cost, delay, mobile traffic characteristics, support for future ultra-high capacity and ultra-dense technologies, upgrading and maintenance challenges, supported cooperative algorithm grades and other factors. Taking into consideration the evolution toward Cloud RAN and the tendency of transmission networks to develop toward higher bandwidth and lower transmission delay, in order to better adapt to future advancements in wireless technology and enhance the vitality of fronthaul interfaces, the NGFI interface should be an evolving interface.

Scheme 5 is a CBR (constant bit rate) service because of its high bandwidth requirement. In application scenarios with plentiful optical fiber resources and conditions for direct deployment of low-cost transmission equipment, the adoption of CPRI-based transmission technology can also meet the needs for centralized BBU deployment. In scenarios in which the number of single-station antennas is relatively small and the remote distance is relatively short (such as indoor deployment), the solution still has its advantages if used in conjunction with RoE (Radio over Ethernet)/CoE (CPRI over Ethernet) technology, because it is possible to leverage existing base station equipment and transmission resources.

Equipment based on partition scheme 1 can be implemented on existing PTN transmission networks to facilitate the deployment of functions with relatively high MAC layer delay requirements onto RRS. This can greatly reduce RCC equipment costs while minimizing impact on transmission networks and existing RCC hardware during migration toward 5G; on existing PTN networks with low hop count or next generation PTN networks with relatively short forwarding delay, equipment based on partition scheme 2 can be directly deployed.
With further advancement of base station virtualization technology toward physical layers, and taking into account future developments and changes in physical layer-based cooperative processing technology, the future demand for partition schemes based on internal physical layers will become increasingly apparent. Because such schemes will require more cross-carrier processing L1 and higher functions to be deployed centrally on the server, only the local processing part needs placement at the remote end. So, for future evolution in wireless technology, it is only necessary to upgrade the software on the server and remote-end devices. This scheme has a relatively high bandwidth requirement and an even more stringent jitter requirement, which cannot be met by existing PTN networks. If deployed on a relatively low-cost transmission network, next-generation PTN network support with high bandwidth and low jitter is needed.

Further research on each potential partition scheme is needed to determine which type of partition scheme to apply to NGFI.
4 MAJOR CHALLENGES AND KEY TECHNOLOGIES FOR REALIZATION OF NGFIS

4.1 RCC-RRS Function Partitioning

Wireless systems include radio frequency and baseband functions, with the latter consisting of protocol functional layers, including a physical layer, a second layer (MAC, RLC, PDCP sublayer, etc.) and a third layer (e.g. RRC). In different wireless network architectures, these functional layers may be distributed over different physical devices and physical entities. To meet the evolving networking needs of future networks, the rational allocation of the functions of each layer between the RCC and RRS is a key consideration in the design of NGFIs.

Function partitioning schemes implemented for current equipment configurations include:

- Integrated base station: all wireless functions are centralized in a physical device, including baseband and RF processing.
- Distributed base station: all protocol functions relating to baseband processing are centralized on the BBU devices; RF-related functions are centralized on the RRUs or on the active antenna system.

Of the two partitioning methods described above, the former is not conducive to realizing cooperative algorithms and functions across base stations, whereas the latter will encounter the problem of excessive bandwidth that renders transmission unsupportable during online network deployment. Therefore, in the NGFI network architecture, it is necessary to rethink the functional partitioning scheme between BBU and RRU (RCC and RRS) to better meet future network evolution requirements. The RCC-RRS function partitioning scheme requires a joint design that combines wireless network technology with fronthaul network technology. It needs to meet wireless network performance requirements and take into account pressure on the fronthaul network. At the same time, the RCC-RRS functional partitioning needs to meet the even greater demands for future wireless network evolution.

4.2 Wireless Data Packetization

Wireless data packetization refers to the transmission of wireless load data between RCC and RRS in the form of data packets. Compared with packaging in the TDM frame format by traditional CPRI interfaces, packetized data transmission provides greater flexibility and scalability, meets the need for high-layer wireless data transmission, enables wireless user loads to be identified and achieves the efficient transmission of wireless user loads and associated control loads in packet-switched networks. To meet the high requirements of wireless data transmission while also retaining the advantages of packetization, achieving packetized transmission based on wireless data characteristics is one of the problems that must be considered in realizing NGFI interface functions in the transmission field.
Given that wireless loads are very sensitive to delay, jitter and synchronization, during packetized transmission, it may be necessary to introduce specific packet headers at the front of wireless loads to deliver in-band control information, such as timestamps or sequential numbers that are needed for wireless load transmission, to facilitate better coordination between the receiving and transmitting ends. Introducing packet headers into wireless loads completes the packetization process, which can be “structure aware” or “structure agnostic.” During the definition process, it is important to study packaging requirements and application scenarios, one or more different specific packet header formats, as well as packaging overheads because of the introduction of packet headers. In addition to focusing on transport layer packaging to provide statistical multiplexing based on the data stream level, synchronization technologies necessary for wireless load transfer will also be a focus of research. Research and capacity building of wireless load packaging technologies need not be related to wireless function partitioning between RRS/RCC. They are also unrelated to specific wireless technologies (2G/3G/4G/5G) and offer relatively good forward compatibility/technological neutrality regarding air interfaces.

Packaged wireless loads are transparent with respect to the transmission network and can be carried by different transmission technologies, including Ethernet switching, MPLS-TP switching, IP routing, L2/L3 MPLS switching and so on. It is necessary to determine how the packaged wireless loads are carried based on the characteristics of each carrier network technology. At the same time, to distinguish such loads from other existing protocol or package types, it may be necessary to introduce new packaging/protocol identifiers for wireless load packaging. Different carrier technology systems vary in terms of their carrying and forwarding efficiency, network/traffic scalability and adaptability, operation and maintenance management capabilities, network/traffic operational viability, industrial chain support level and so on. Appropriate choices should be made based on the overall strategy of the transmission network, together with the technical characteristics of each transmission technology.

### 4.3 Main Challenges of NGFI Transmission

#### 4.3.1 NGFI Transmission Delay

NGFI interface RCC-RRS data transmission delay is defined as the total time required for transmission and switching of data from RCC network interfaces to RRS network interfaces, and the time symmetry required for uplink and downlink. Compared with traditional CPRI interfaces, new NGFI interfaces will create additional delay losses, mainly due to the additional switching delay of switched network devices. Given that current LTE protocols require the interaction time of HARQs (Hybrid Automatic Repeat Requests) on the UE (user equipment) side and system side to be fixed, if RCC-RRS functional partitioning points are placed within the HARQ process, this will entail both a data transmission delay and a data processing delay. Therefore, if the transmission delay is extended, it will then be necessary to shorten the processing delay, which will place higher demands on RCC chip processing capacity. If RCC-RRS functional partitioning points are placed
outside the HARQ process, there will be too many functions preceding the remote location, which will affect multi-carrier cooperative performance. Therefore, transmission delay is considered a key factor in NGFIs.

4.3.2 NGFI Transmission Jitter

NGFI interface transmission jitter is defined as the fluctuation in the time taken for data to be transmitted from the RCC network interface to the RRS network interface. Transmission jitter is mainly reflected in two aspects. First, the wireless equipment on both sides needs to implement data caching to compensate for jitter. The greater the jitter, the bigger the data buffering space and the more complex the equipment. Second, the baseband's actual processing time sequence must be designed according to the latest data arrival time. The greater the jitter, the shorter the time left for baseband processing.

If the NGFI is based on Ethernet transmission, and the presence of transit nodes further increases traffic message jitter; to guarantee wireless performance, transmission devices must be specially designed or optimized to reduce jitter and meet the jitter requirements of the NGFI.

4.3.3 NGFI Synchronization Issues

The potential NGFI synchronization scheme includes the introduction of GPS or the BeiDou system on the RAU side and synchronization via fronthaul networks. If the synchronization scheme adopts GPS or the BeiDou system on the RAU side as the synchronization source, the impact of the NGFI will be relatively small. If it adopts clock synchronization from the fronthaul network, it is necessary to carefully consider the requirements of the synchronization clock with respect to the fronthaul network. Synchronization accuracy is related to the size of the fronthaul network and performance of the transmission equipment. Under normal circumstances, the fronthaul network needs to support SyncE and 1588v2.

- **Phase Synchronization Requirements**

Backhaul networks with traditional BBUs must fulfill the need for air interface downlink synchronization of the TDD system. According to the 3GPP definition, air interface accuracy must reach +/- 1.5 µs. Using the 1588v2 protocol to achieve synchronization between different stations, nanosecond synchronization accuracy is possible. Considering the additional loss of accuracy that BBU data processing could entail, China Mobile's existing network requires that backhaul networks provide the following time synchronization accuracy: the time error introduced by PTN equipment after 30 hops cannot exceed 1 µs.

Further considering the needs of physical layer cooperative technology, synchronization errors between different antennas of different RRUAs (RRUs in the same site or RRUs in different sites) must be less than 130 ns in order to support downlink joint delivery functionality between multiple RRUs. If carrying out physical layer cooperation across RRSs, this indicator will place higher demands on existing networks, so fronthaul transmission networks must be designed in conjunction with wireless networks.

- **Frequency Synchronization Requirements**
NGFI interfaces have higher frequency synchronization requirements compared with traditional interfaces. Backhaul networks with traditional BBUs adopt Synchronous Ethernet (SyncE) technology to achieve frequency synchronization. The macro station frequency synchronization index is defined as 0.05 ppm to meet the frequency synchronization error requirements of LTE wireless air interfaces. In the NGFI environment, RRSs can acquire frequency synchronization through the fronthaul network SyncE.

4.3.4 NGFI Transmission Bandwidth

To provide a good user experience, fronthaul networks must guarantee a certain bandwidth in order to support the RCC input/output data rate.

4.4 Impact of Introducing NGFIs

4.4.1 Impact of NGFIs on the RRU side

Compared with traditional RRUs, the support NGFI protocol increases complexity on the RRU side to some extent, mainly in terms of the following three aspects:

- It moves the wireless part's protocol stack function and algorithmic processing function to the RRU side.
- It increases the number of clock synchronization modules to achieve 1588v2/SyncE.
- It expands the existing BBU-RRU peer-to-peer connection modes. Given the networking needs of fronthaul networks, it is necessary to regard each RRS as a network element and add extra RRS management functions.
- For integrated RRS, moving part of the baseband processing functionality to the RRS side increases the heat dissipation, size and weight of the RRS, thereby having greater impact. The size, weight, heat consumption and transmission power level of the RRS are closely interrelated; according to current RRS cooling capacity estimates, at a high temperature limit, heat volume is approximately 15 W/L for each additional 15 W of power consumption. Compared with existing RRUs, this is estimated to increase RRS volume by 1 L, with a corresponding weight increase of about 1 kg.

4.4.2 Impact of NGFIs on Transmission Networks

Transmission equipment supporting NGFIs should offer greater bandwidth, low delay and low jitter, support high time synchronization accuracy, be inexpensive and provide a high level of integration. Networks must take into account packet loss rate, delay, jitter and other parameters. Various functional partitioning schemes place different demands on NGFI network transmission in terms of packet loss rate, delay and jitter, as do different types of data within a given partitioning scheme.
Packet loss rate: traffic congestion in the NGFI wireless fronthaul network should be avoided, for example, by supporting QoS.

Low delay: to control delay, there are limitations on transmission distance and hops in NGFI wireless fronthaul networks.

Jitter: should be minimized as much as possible.

From the above application scenario, it can be seen that requirements for NGFI networking differ greatly from those for current backhaul networks, so the utilization of existing backhaul networks (PTNs) for transmission of NGFI data presents major challenges.

Now that PTNs used as transmission carrier networks place emphasis on full-process networks, traffic may need to be organized across tens or even hundreds of kilometers; networks cover a wide area, and traffic is transported over long distances. Access devices use shared site mode with BBU sites whenever possible. PTN networks are used for both mobile backhaul and leased-line traffic services for large customers. However, fronthaul and backhaul networks are organized quite differently. First, fronthaul networks are based on BBU pools, cover a small area, involve short transmission distances, and are divided into a number of independent islands in the horizontal direction, with no interference between traffic. Second, they have a high number of distributed RRU sites spaced closely together, not necessarily with an access equipment room, and with a smaller overlap than existing PTN access equipment rooms. Therefore, the network infrastructure and distribution mean that it is not possible to fully reuse existing PTN networks.
5 DEFINITION OF NGFI REQUIREMENTS

Based on a comprehensive discussion and consensus on the analysis of the potential schemes in chapter 3, this chapter should propose index requirements for the agreed schemes. At present, this chapter only provides functional definitions of NGFI: the definition of specific performance indicators needs further improvement.

5.1 NGFI Wireless Interface Requirements

5.1.1 Data Packaging Requirements

Four types of data streams must be supported on NGFI interfaces:

- Wireless user plane packets
- Control management packets
- Synchronous packets (SYNC-E SSM, IEEE1588v2)
- OAM packets

5.1.2 Synchronization Requirements

Because ultimately the frequency synchronization accuracy of macro station air interfaces must meet 0.05 ppm, the time synchronization target accuracy is +/- 65 ns (TBD). Therefore, the frequency synchronization accuracy for NGFI interfaces between RCC-RRS is provisionally set to *** ppm (TBD), and, currently, the time synchronization accuracy is provisionally set to *** ns (TBD). In follow-up NGFI studies, relevant models will be established for further analysis.

5.1.3 Bandwidth Requirements

NGFI uplink and downlink transmission bandwidth is related to the adopted wireless function partitioning scheme and depends on the number of carriers and channel bandwidth; in certain partitioning schemes, it is also related to the number of antennas. See Table 3-1 for the transmission bandwidth requirements of different partitioning schemes. The transmission bandwidth requirements for NGFIs are:

- NGFI downlink transmission bandwidth not exceeding *** Mbps. (TBD)
- NGFI uplink bandwidth not exceeding *** Mbps. (TBD)

5.1.4 Maximum Delay Requirements

The front-end transmission network should support at least 6 hops and the one-way transmission delay should not exceed a maximum total of *** µs (TBD).

This includes a maximum optical fiber transmission delay not exceeding 100 µs (related to the maximum supported transmission distance).
5.1.5 Transmission Distance Requirements
Fronthaul networks should support a maximum transmission distance of 20 km.

5.1.6 Jitter Requirements
For NGFI packet data, the front-end transmission network should support up to 6 hops, with a maximum one-way jitter not exceeding 60 µs (TBD).

5.1.7 Loss Ratio Requirements
TBD

5.1.8 Transmission Delay Measurement and Calibration
Provides the ability to report peer-to-peer transmission delay measurements between RCC-RRS, provides the necessary indicative information for the upper-layer, wireless-side protocol stack software. Delay measurement should initiate automatically when the equipment is powered on or when the channel setup is transferred between the RCC and RRS; it can also be initiated manually by the network administrator.

5.1.9 QoS Requirements
RCC and RRS should be able to carry out QoS marking of data packets transferred on NGFI interfaces.

5.1.10 C&M Requirements
NGFI interfaces should be able to provide C&M channels to facilitate RRS control and management by the RCC.

5.1.11 OAM Requirements
NGFI interfaces should be able to support Ethernet OAM functions compliant with Y.1731/IEEE802.1ag in order to achieve NGFI interface fault detection, fault location and performance monitoring between RCC and RRS.

5.2 NGFI Fronthaul Network Load Requirements
This section temporarily puts forward recommendations for PTN-based schemes[5].

5.2.1 Operational Load Requirements
Wireless plane data packets and C&M plane packets of NGFI interfaces prioritize the use of E-Line (VPWS) carriers but can also use E-LAN (VPLS) mode carriers.

5.2.2 Data Forwarding and Statistical Multiplexing Requirements
Transmission equipment for carrying NGFIs should support MPLS-TP-based data forwarding and statistical multiplexing.
5.2.3 QoS Requirements

Transmission equipment for carrying NGFIs should conduct service-level mapping based on the priority and color in the NGFI messages, achieving DiffServ per-hop behavior (PHB).

5.2.4 Synchronization Requirements

Frequency synchronization of transmission equipment for carrying NGFI should adhere to G.8262/G.8264 EEC Option 1, whereas time synchronization should adhere to IEEE1588 and China Mobile’s PTN-related corporate standards.

5.2.5 Delay Requirements

When there is no blockage, the single-hop delay of transmission equipment used to carry NGFIs should not exceed 20 μs (TBD).

5.2.6 OAM Requirements

Transmission equipment for carrying NGFIs must comply with the OAM function of the Ethernet service layer and MPLS-TP layer, as required by China Mobile’s PTN specifications.

5.2.7 Protection Switching Control

Transmission equipment for carrying NGFIs should support the network protection mechanisms required by China Mobile’s PTN specifications, including MPLS-TP ring, linear protection and dual-homing protection, with a transport protection switching delay of less than 50 ms.

5.2.8 Loss Ratio Requirements

When throughput does not exceed 90%, the packet loss rate should be 0 for high-priority data packets and no more than 1 × 10⁻⁷ for non-high priority packets.

5.3 Equipment Configuration Requirements

5.3.1 Wireless Equipment Configuration Requirements

5.3.1.1 RRS Equipment Requirements

Where possible, an outdoor equipment configuration should be selected for new remote RRSs after functional repartitioning. Furthermore, because outdoor interfaces and connected transmission equipment are exposed to the weather, it is necessary to improve their watertightness and airtightness and implement other measures to ensure their reliability.

5.3.1.2 RRS Synchronous Implementation Requirements

RRS frequency synchronization is derived from the fronthaul network, so macro station air interfaces must meet a synchronization accuracy requirement of 0.05 PPM.
RRS time synchronization derives from external Ethernet-1588v2 protocols so must meet a requirement of +/-65 ns.

5.3.1.3 RCC Synchronous Implementation Requirements
RCC frequency and time synchronization can derive from external transmission networks or GPS/BeiDou.

5.3.1.4 Network Management Function Requirements
RRS and RCC are treated as peer network elements, with unified resource management; correspondence between RCC and RRS may be reassigned through network management configurations.

5.3.1.5 RRS Forward Compatibility Requirements
RRSs should provide support for both NGFIs and traditional CPRIs.

5.3.2 Transmission Equipment Configuration Requirements
Transmission equipment supporting NGFIs can be PTN, Ethernet switches and other packet switching equipment.

For cross-connect capacity: taking as an example a wireless fronthaul network that supports on the order of one hundred carriers, assuming it has a ring setup, where N is the number of carriers carried on the ring, BW is the transmission bandwidth required for each carrier fronthaul, CR is the packaging network convergence ratio, and LB is the local base station uplink and downlink traffic bandwidth, and taking into account protection requirements, the required cross-capacity is BW*N*CR^2+LB. If there are 100 carriers, each carrier needs 1 G of bandwidth, a convergence ratio of 1/3, and 10 G local base station uplink and downlink traffic bandwidth, so the required cross capacity is 78 G.

For the port speed: 100 G ports must be supported in accordance with the above model. For local base station uplink and downlink traffic, 1-G and 10-G ports must be supported.

To save floor space, transmission equipment supporting NGFIs can be integrated into wireless equipment in module or board format at the remote or local end.

6 SUMMARY
Because of their peer-to-peer transmission model, fixed-rate transmission characteristics and other reasons, traditional fronthaul interfaces, such as CPRIs, suffer from low transmission efficiency, poor scalability and limited flexibility, making them unsuitable for future wireless network architecture. As wireless networks evolve toward 5G, traditional fronthaul interfaces need redesign.

This white paper describes China Mobile’s thinking, design criteria and developments with regard to next-generation fronthaul interfaces (NGFI) and formulates NGFI requirements. The design of NGFIs must take into consideration both wireless and transmission levels. On the wireless level, functional repartitioning must be carried out on BBU and RRUs, bearing in mind that total data throughput varies depending on the actual
number of service users, and utilizing packet-oriented statistical multiplexing to reduce overall transport costs. On the other hand, it is necessary to consider wireless cooperative performance requirements: for example, through centralization, it is possible to achieve BBU functions with high cooperative gain in the BBU resource pool and move no-cooperative gain or low cooperative gain functions to the RRU after centralized processing, distributing them to the remote end in order to achieve maximum wireless gain. In addition, NGFI bandwidth should be independent of antennas to better support 5G multi-antenna technology.

On the transport level, NGFI requires interface packetization to facilitate the use of Ethernet networks for transmission, thus achieving a flexible connection relationship between RCC and RRS. How to implement support for NGFI data, especially as regards delay, jitter and synchronization, is a major challenge for the design of Ethernet transmission networks.

Through this white paper, we invite all mobile operators, telecom equipment manufacturers and traditional IT system manufacturers, as well as industrial and academic research institutions that are focused on the future evolution of fronthaul networks, to actively participate in the research of key NGFI technologies, with a view to turning the NGFI vision into reality.
<table>
<thead>
<tr>
<th>Abbreviation</th>
<th>Full Form</th>
<th>Meaning</th>
</tr>
</thead>
<tbody>
<tr>
<td>NGFI</td>
<td>Next Generation Fronthaul Interface</td>
<td>下一代无线电前传接口</td>
</tr>
<tr>
<td>BBU</td>
<td>Baseband Unit</td>
<td>基带单元</td>
</tr>
<tr>
<td>HARQ</td>
<td>Hybrid Automatic Repeat Request</td>
<td>混合自动重发请求</td>
</tr>
<tr>
<td>RRU</td>
<td>Remote Radio Unit</td>
<td>远端射频单元</td>
</tr>
<tr>
<td>CPRI</td>
<td>Common Public Radio Interface</td>
<td>通用公共无线电接口</td>
</tr>
<tr>
<td>C-RAN</td>
<td>Centralized, Cooperative, Cloud RAN</td>
<td>集中式/协作式/云计算无线接入网</td>
</tr>
<tr>
<td>3GPP</td>
<td>the 3rd Generation Partner Project</td>
<td>第三代合作伙伴计划</td>
</tr>
<tr>
<td>RCC</td>
<td>Radio Cloud Center</td>
<td>无线云中心</td>
</tr>
<tr>
<td>RAU</td>
<td>Radio Aggregation Unit</td>
<td>射频聚合单元</td>
</tr>
<tr>
<td>Sync-E</td>
<td>Synchronous Ethernet</td>
<td>同步以太网</td>
</tr>
<tr>
<td>RRS</td>
<td>Remote Radio System</td>
<td>远端射频系统</td>
</tr>
<tr>
<td>UE</td>
<td>User Equipment</td>
<td>用户设备</td>
</tr>
<tr>
<td>RB</td>
<td>Resource Block</td>
<td>资源块</td>
</tr>
<tr>
<td>CoMP</td>
<td>Coordinated Multi-point Processing</td>
<td>协作多点传输技术</td>
</tr>
<tr>
<td>CS</td>
<td>Coordinated Scheduling</td>
<td>联合调度</td>
</tr>
<tr>
<td>JR</td>
<td>Joint Reception</td>
<td>联合接收</td>
</tr>
<tr>
<td>JT</td>
<td>Joint Transmission</td>
<td>联合发送</td>
</tr>
<tr>
<td>MCS</td>
<td>Modulation and Coding Scheme</td>
<td>调制与编码策略</td>
</tr>
<tr>
<td>PTN</td>
<td>Packet Transport Network</td>
<td>分组传送网</td>
</tr>
<tr>
<td>PON</td>
<td>Passive Optical Network</td>
<td>无源光纤网络</td>
</tr>
<tr>
<td>WDM</td>
<td>Wavelength Division Multiplexing</td>
<td>波分复用</td>
</tr>
</tbody>
</table>
REFERENCES

ACKNOWLEDGMENTS

Our sincere thanks to the following institutions and authors for their contributions to this white paper:

China Mobile Research Institute: Yi Zhiling, Cui Chunfeng, Li Han, Han Liuyan, Huang Jinri, Duan Ran, Yuan Yannan, Ma Shijia, Sun Junshi, Kong Lingbin, Cheng Weiqiang

Alcatel-Lucent: Zhang Xiaowen, Jiang Xiaogen, Liu Fangxin

Nokia Networks: Yu Fei, Wu Zhiyuan, Xu Xiaolin

ZTE Corporation: Xiang Jiyan, Li Yujie

Broadcom Corporation: He Zongying

Intel China Research Center: Zhang Xu, Zhou Feng