5G Network Evolution and Dual-mode 5G Base Station

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Abstract—**The fifth generation (5G) networks can provide lower latency, higher capacity and will be commercialized on a large scale worldwide. In order to efficiently deploy 5G networks on the basis of the existing Long Term Evolution (LTE) networks, dual-mode 5G base station is a potential technology which can support Non-standalone (NSA) and Standalone (SA) network access. This paper focuses on the principles of the dual-mode 5G base station based on a comprehensive review of the 5G network architecture and evolution. Combined with the field trial data, the performance of the dual-mode 5G base station was analyzed. Finally, some practical suggestions on the deployment of dual-mode 5G base stations for operators are proposed.**

Keywords-5G deployment;Dual-mode base station; Non-standalone (NSA); Standalone (SA);Field trial

I. INTRODUCTION

The fifth generation (5G) includes two network architectures: Non-standalone (NSA) and Standalone (SA). NSA network focuses on enhanced mobile broadband (eMBB) to provide increased data-bandwidth and connection reliability. In NSA network, the radio part is 5G New Radio (NR) and the core part is the fourth generation (4G) Evolved Packet Core (EPC). Compared with the NSA mode that only supports large-bandwidth services, SA network can provide thousands of industries with 5G network ultra-low latency, end-to-end network slicing and other features [1].

Since the 5G network must complete the transition from NSA to SA network, in order to achieve the smooth evolution of 5G network and reduce network construction investment, recently a NSA/SA dual-mode 5G base station has been proposed. The dual-mode 5G base station can support both NSA and SA user equipment (UE) access. The deployment of dual-mode base stations can enable telecom operators to ensure the rapid commercial application of the 5G NSA network in the future 5G network construction, but also being able to cope with the 5G network from the rapid handover and smooth evolution of NSA to SA so as to finally achieves 5G full service scenarios. Therefore, the deployment of dual-mode 5G base stations for future 5G mobile network is very important and becomes the main focus of our work.

Motivated by the above discussion, this paper first investigates NSA and SA network and evolution. On this basis, the dual-mode 5G base station technology is introduced. Furthermore, through the field trial results of the dual-mode 5G base station, some practical recommendations for telecom operators to build the 5G networks.

The rest content of this paper is organized as follows. Section II compares the NSA and SA network. The dual-mode 5G base station technology is proposed in Sections III. Section IV provides the field trial results of the dual-mode base stations. Finally, Section IV concludes the paper and gives some practical suggestions on the deployment of dual-mode 5G base stations.

II. 5G NETWORK ARCHITECTURE

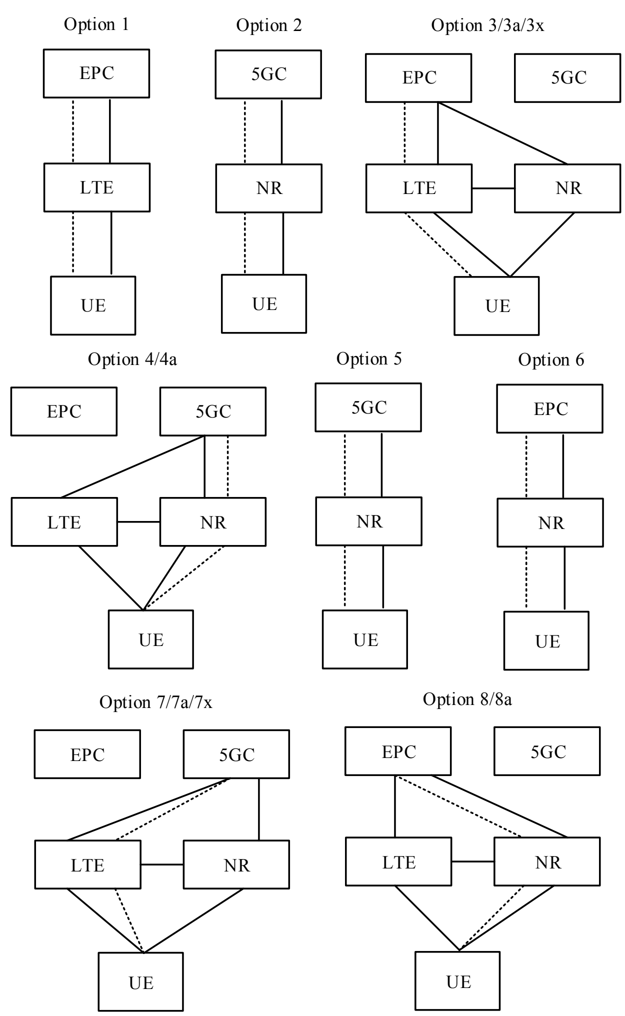

Figure 1. 5G deployment options.

The 3rd Generation Partnership Project (3GPP) has introduced Dual Connectivity (DC) mechanisms in 5G Radio

Access Network (RAN) [2]. Thus the 5G network architecture is more complex and flexible than 4G. At the 72nd plenary meeting of 3GPP RAN, eight networking architecture were proposed based on the different requirements of the network deployment, as shown in Figure 1 (solid lines indicate service flows and dashed lines indicate control flows) [3]. In these deployment options, option 1, 2, 5 and 6 are SA network, while option 3, 4, 7 and 8 are NSA network.

NSA network doesn't require 5G core network (5GC), they rely on Long Term Evolution (LTE) network as an anchor point, which has the advantage of fast deployment, allowing operators to quickly realize large-bandwidth services in the early stages of 5G. However, in order to meet the needs of vertical industry applications, the SA architecture is the operator's future target network. The reason is SA network can not only meet the full business requirements of eMBB, URLLC (Ultra-Reliable Low-Latency Communication) and mMTC (massive Machine Type Communications), but also supports new features such as network slicing and edge computing [4]. For most operators, the common choice for NSA is option 3, and the common choice for SA is option 2.

Option 3 series network architecture adopts the dual connection of 4G base station (eNB) as the master node and 5G base station (gNB) as the secondary node, which is called EN-DC (EUTRA-NR Dual Connection). In the EN-DC dual connectivity, the UE is connected to the eNBa and gNB at the same time, where the eNB is connected to the mobility management entity (MME) and S-GW through the S1-MME and S1-U interfaces respectively. Also the eNB is connected to gNB through the X2-C and the X2-U interface, and gNB is connected to the S-GW through the S1-U interface, as shown in Figure 2.

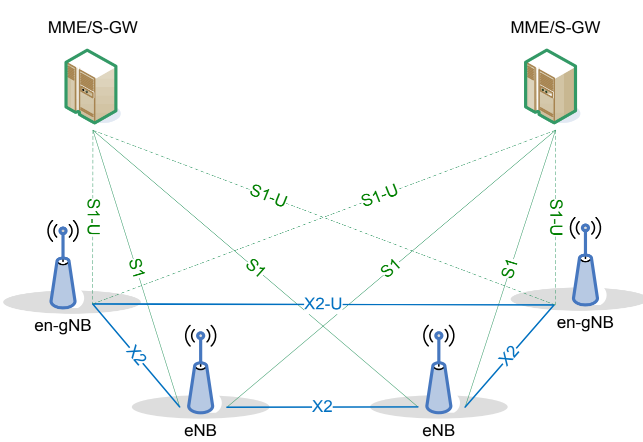

Figure 2. NSA network.

All control plane signaling of option 3 is forwarded via the eNB. Option 3 series network architecture can be divided into three sub-options of option 3/3a/3x, and the data offload is performed through eNB/EPC/gNB respectively. Among these three sub-options, option 3 has higher requirements on the throughput of LTE base stations and the transmission of the X2 interface with 5G NR base stations; Option 3a requires LTE base stations to have a more flexible mechanism to dynamically select the anchor point of the user bearer but the transmission requirements for the X2 interface are relatively low; Option 3x is directly connected to the MME through the 4G base station as the anchor point on the control plane. The user data traffic distribution and aggregation is completed at the 5G base station, and the 5G base station can be directly transmitted to the terminal. It can also forward part of the data to the 4G base station through the X2-U interface and then transmit it to the terminal. In summary, the Option 3x network can make full use of the coverage of the existing 4G network as the control plane transmission of the network, so operators generally use this solution to deploy NSA network [5].

In option 2 architecture, as shown in Figure 3, the 5G core network and the 5G base station are directly connected through the NG interface to transmit non-access stratum (NAS) signaling and data. The RRC signaling, broadcast signaling, and data of the 5G wireless air interface are directly transmitted through the NR air interface of the 5G base station. Option 2 architecture has no impact on the existing 2G/3G/4G network architecture, and 5G new network elements can be deployed independently. Option 2 architecture supports 5G core network capabilities, and can provide the ability to support enhanced mobile broadband and basic low-latency and high-reliability services, provide differentiated services for different services to facilitate the expansion of vertical industry applications [6].

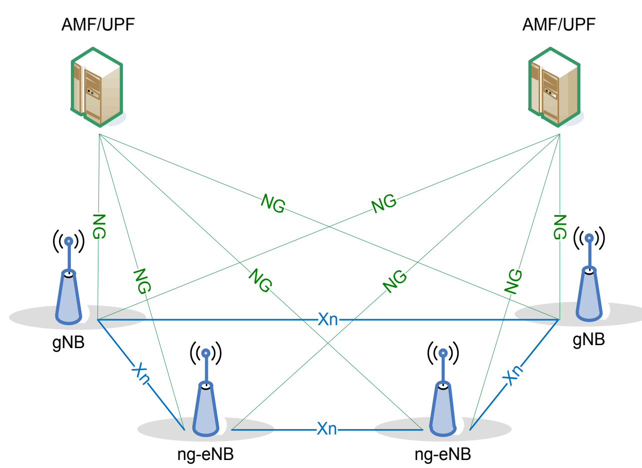

Figure 3. SA network.

The main difference between NSA and SA network is that NSA anchors the control signaling to the 4G base station, and the SA base station is directly connected to the 5GC. Although SA network is the target 5G network, operators can also deploy NSA/SA dual-mode networks to support both NSA and SA users access, because 1) the NSA industry chain matures before SA; 2) there exist the roaming needs of international NSA users [7]. Due to the NSA and SA network are basically the same on the NR air interface protocol, there are only certain differences in the high-level protocol of the wireless network, so it is possible to support both NSA and SA networking through dual-mode 5G base stations.

III. Dual-mode 5G Base Station Technology

A. Dual-mode 5G Base Station Architecture

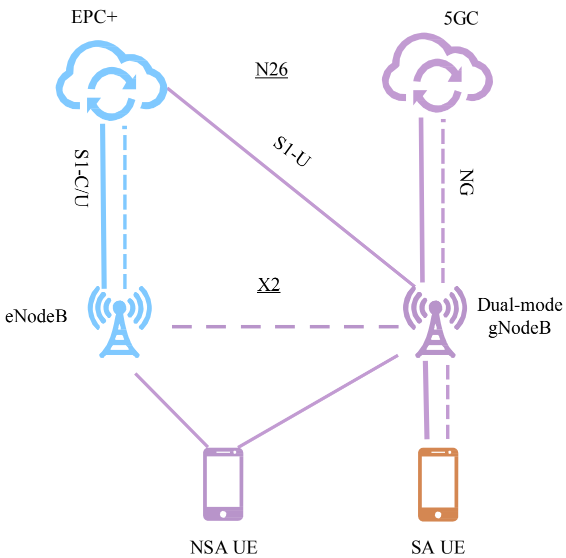

Figure 4. Dual-mode 5G base station.

The dual-mode 5G base station runs both option 3 and option 2 architectures, which can support both SA and NSA terminal access. As shown in Figure 4, the dual-mode 5G base station is connected to the 5GC through the NG interface, that is, the NC-C interface is connected to the access and mobility management function (AMF), and the NG-U interface is connected to the user plane function (UPF). The dual-mode base station can be connected to the EPC through the S1 interface and connected to the eNB through the X2 interface. EPC and 5GC can be connected through N26 interface [8].

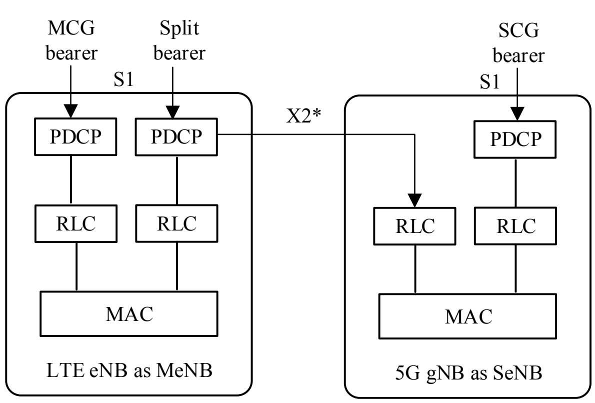

Figure 5. dual-mode 5G base station wireless bearer.

For users accessing dual-mode 5G base stations in NSA mode, LTE eNB serves as the master base station (Master eNB, MeNB), and 5G gNB serves as the secondary base station (Secondary eNB, SeNB). According to different data separation and forwarding methods, as shown in Figure 5, the radio bearer of dual-mode 5G base station is divided into three forms [9]:

Master Cell Group (MCG) bearer: MCG bearer is the traditional bearer mode. The MCG bearer is routed from the S-GW of the core network to the MeNB, and is directly forwarded to the UE by the MeNB, that is, data is forwarded only from the LTE side.

Secondary Cell Group (SCG) bearer: The SCG bearer is routed from the S-GW of the core network to the SeNB, and then forwarded by the SeNB to the UE, that is, data is forwarded only from the NR side of the dual-mode base station.

Split bearer: Data flow is separated at Packet Data Convergence Protocol (PDCP) layer, MeNB and SeNB are responsible for forwarding data to the UE simultaneously according to a certain proportion, that is, LTE and NR complete data forwarding together. Users obtain downlink data from the two networks, which facilitates load sharing and resource coordination, and also helps to increase throughput. The disadvantage is that the PDCP layer protocol need to realize the flow control according to the transmission requirements between the LTE and NR base stations, which lead to high complexity.

The bearer separation of the dual-mode 5G base station is performed at the PDCP layer, and the two access points can independently schedule the physical layer resources. If the dual-mode base station turns off data split mode, it can be simplified to separate scheduling for the LTE and NR MAC layers, priority scheduling for NSA and SA users on the NR side, and LTE side scheduling only for LTE users.

B. Dual-mode Base Station Access and Handover

During initial access, the dual-mode base station prefers SA mode access for SA terminals, and automatically camps on 5G cells after the successful access, otherwise it falls back to LTE. While as for NSA terminals, the priority access is LTE network, and choose LTE only or NSA access according to the dual-mode base station coverage.

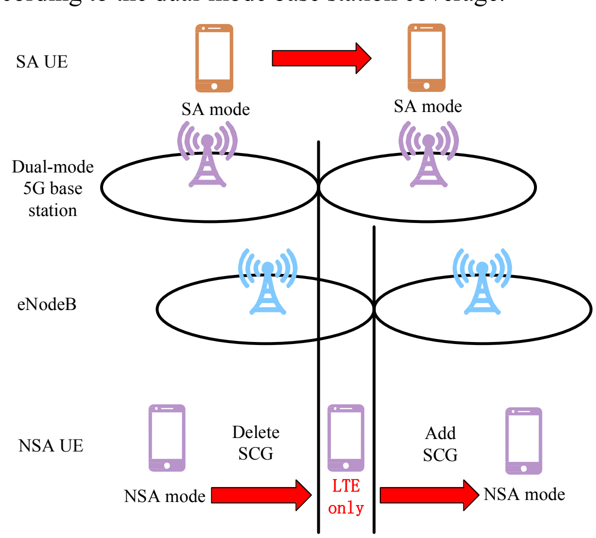

Figure 6. SA and NSA UE switching.

As shown in Figure 6, due to the differences in the coverage of the LTE base station and the dual-mode 5G base station, for NSA users, there exist 5G carrier added and deleted process at the cell edge of the dual-mode base station, while SA users only have NR switching when the cell coverage is continuous.

C. Dual-mode Base Station Networking

The dual-mode 5G base stations can be connected through the Xn interface mutually, and connect through the X2 interface with the LTE base station. The dual-mode base station provides SA UE with NR user plane and control plane connections through the NR new air interface. For NSA terminals, the LTE eNB serves as the MeNB, and the dual-mode 5G base station serves as the SeNB [10].

There are two specific networking methods for dual-mode base stations:

1. Dual-mode base station connected network. The dual-mode base station is continuously deployed. LTE base stations with the same coverage in the dual-mode base station area need to be upgraded to support the related functions of the dual-mode base station on the LTE side. The terminal needs to be able to normally switch between dual-mode base stations.

2. The dual-mode base station is adjacent to the NSA/SA base station. The dual-mode base station is deployed in the NSA/SA network in a floral arrangement. Similarly, LTE base stations with the same coverage in the dual-mode base station area need to be upgraded to support the related functions of the dual-mode base station on the LTE side. The terminal needs to be able to normally switch between the dual-mode base station, and between the dual-mode base station and the SA/NSA base station.

D. Advantages and Disadvantages of Dual-mode Base Stations

The mode conversion of dual-mode base station can be realized through software configuration. When the network evolves from NSA to SA, only the software configuration of the base station needs to be upgraded, so that the operator can finish the investment in hardware in one step and achieve long-term evolution [11]. In addition, the dual-mode base station can support two types of terminal access on one carrier, that is, when the network is finally upgraded to SA, end users do not need to replace their mobile phones, which allows the real smooth evolution to be completed.

But on the other hand, dual-mode 5G base station functions are more complex, making optimization and maintenance difficult. The dual-mode 5G base station needs to support all the functions of the NSA and SA base stations. It not only needs to support interconnection with the existing 4G network to realize NSA network function, but also to deploy a 5G core network to support the new functions of SA network. At the same time, the dual-mode 5G base station networking needs to consider the joint optimization of 4G and 5G, which increases the complexity and optimization difficulty of the network. Moreover, the dual-mode 5G base station needs to maintain the X2, NG and S1 interfaces, complete two sets of parameter configuration for NSA and SA network and cope with various optimization or maintenance issues, which is a heavy workload for the operators.

IV. Field Trial of Dual-mode Base Station

To evaluate the basic properties of the dual-mode 5G base station, the performances of both throughput and delay are evaluated by the field trial. The basic parameter configuration is listed in Table 1. In field trial, under fixed power transmission of the base station, the trial geographic location points are selected in the test cell with different channel conditions signal-to-noise-plus-interference ratio (SINR). The near, middle and far points are defined as the UE received SINR=15~20dB, SINR=5~10dB and SINR=-5~0dB respectively [12].

TABLE I. Basic Parameter Configuration

frame structure	2.5ms dual periodicity (DDDSU+DDSUU)
special slot format	10:2:2
center frequency	3450 MHz
bandwidth	100 MHz
subcarrier spacing	30 KHz
ACK/NACK mode	adaptive
PDCCH symbol	1 symbol
feedback type	PMI/CQI/RI/CRI
number of antennas	64T64R

A. Field Trial Results

Figure 7 shows the downlink fixed-point trial results of dual-mode 5G base stations. From the figure, at the far, middle, and near points, the downlink rate of the SA terminal is better than that of the NSA. It is obvious that the rate of NSA Split mode is higher than that of NSA SCG mode because the rate of NSA Split mode can be shunted from the LTE side. At the near point, the rate of the SA terminal is twice that of the NSA terminal. Although the SA terminal and NSA terminal both have four receive antennas, the NSA terminal achieve two streams while the SA terminal achieve four streams in field trial because the NSA terminal needs two antennas to connect to the LTE base station.

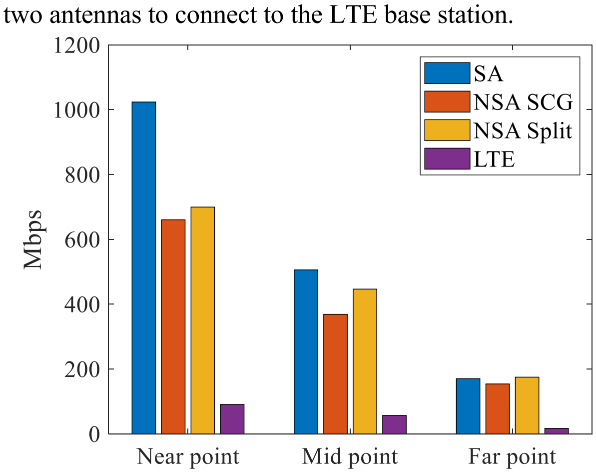

Figure 7. Field trial results with downlink fixed-point.

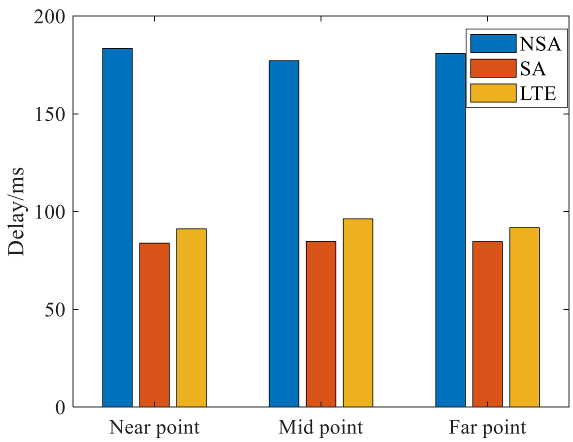

Figure 8. Field trial results of control plane delay.

As shown in Figure 8, the data of the control plane is obtained by averaging ten fixed-point trial results. There is no obvious difference between the near, middle and far points. Statistics SA average control plane delay is about 84ms, which is lower than that of LTE and NSA. The average control plane delay of LTE is about 93ms, and The average control plane delay of NSA is about 180ms. The LTE terminal control plane delay is almost the same as the SA terminal control plane delay, but the NSA terminal control plane delay is higher, which is equivalent to the sum of LTE and SA control plane delay. The main difference is that NSA terminals need to perform twice UE capability level queries when accessing the dual-mode 5G base station, including LTE capabilities and NR capabilities, resulting in the control plane delay increases. But the SA terminal and the LTE terminal only need to perform once UE capability query.

B. *Impact of Dual-mode Base Stations on Existing Networks*

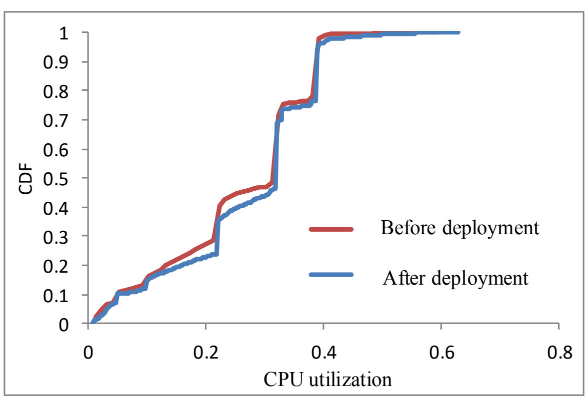

Figure 9. CPU utilization changes before and after the dual-mode 5G base station deployment.

Figure 9 shows the changes in CPU utilization before and after the dual-mode 5G base station is deployed. The two curves fluctuate slightly and almost coincide, which indicates there is no significant increase in the load of the base station. The CPU utilization rate remains basically the same. According to the field trial results of the performance indicators of the existing network, the deployment of the dual-mode 5G base station has no significant impact on the current LTE networks.

V. Conclusion

In this paper, based on a comprehensive study of the 5G network evolution, a dual-mode 5G case station was proposed and analyzed to meet the both NSA and SA UE access simultaneously. Furthermore, a field trial was conducted to evaluate the performance of the dual-mode 5G case station. The obtained results show that the dual-mode 5G case station can well meet the throughput and delay requirements of the NSA and SA terminals, and the deployment of the dual-mode 5G base station has no significant impact on the existing LTE networks.

The construction of the 5G network will take a long time to complete. The dual-mode 5G base station enables the 5G network to evolve from NSA to SA smoothly. Telecom operators can preferentially deploy the dual-mode 5G base stations to use NSA mode to support eMBB services. After the industry chain matures, the 5G core network can be further deployed to meet the needs of more scenarios.

Acknowledgment

This work is supported by the key research project of China Telecom: "5G co-construction and sharing of end-to-end network solutions and key technology development and deployment applications" (No. 20HQBYYF0026-001)

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