Chongqing University of Posts and Telecommunications

&

Brunel University London

Final Report

Semester：	2024 Fall term
Course name：	Mobile Network Workshop (Major Internship)
	School of Communication and Information Engineering
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Course	Major Internship	**Course code**	**A2011261**
Place	**YF304**	**Course time**	**Week 1-Week 4, Week 6, Week 8**
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Score			

I. **OBJECTS**

1. Knowledge of the structure of LTE and 5G networks is essential.
2. Mastery of 4G network topology planning, capacity planning, and estimation methods is important.
3. Knowledge of the configuration methods for each network element in the 4G network is required.
4. Understanding the meaning and function of the docking configuration data for each 4G network element is essential.
5. Awareness of the networking mode of the 5G network, along with mastery of the configuration methods for each network element in Option 3X mode in NSA mode, is important.
6. Understanding the significance and function of related data, such as QoS, frame structure, 5G wireless parameters, and physical channels, is crucial.
7. Ability to analyze and solve faults is necessary.
8. Practical application skills in communication network engineering should be developed.

II. **Tools**

IUV-Pre5G and IVU-5G online simulation software

III. **REPORT**

1. **Network extension planning map**

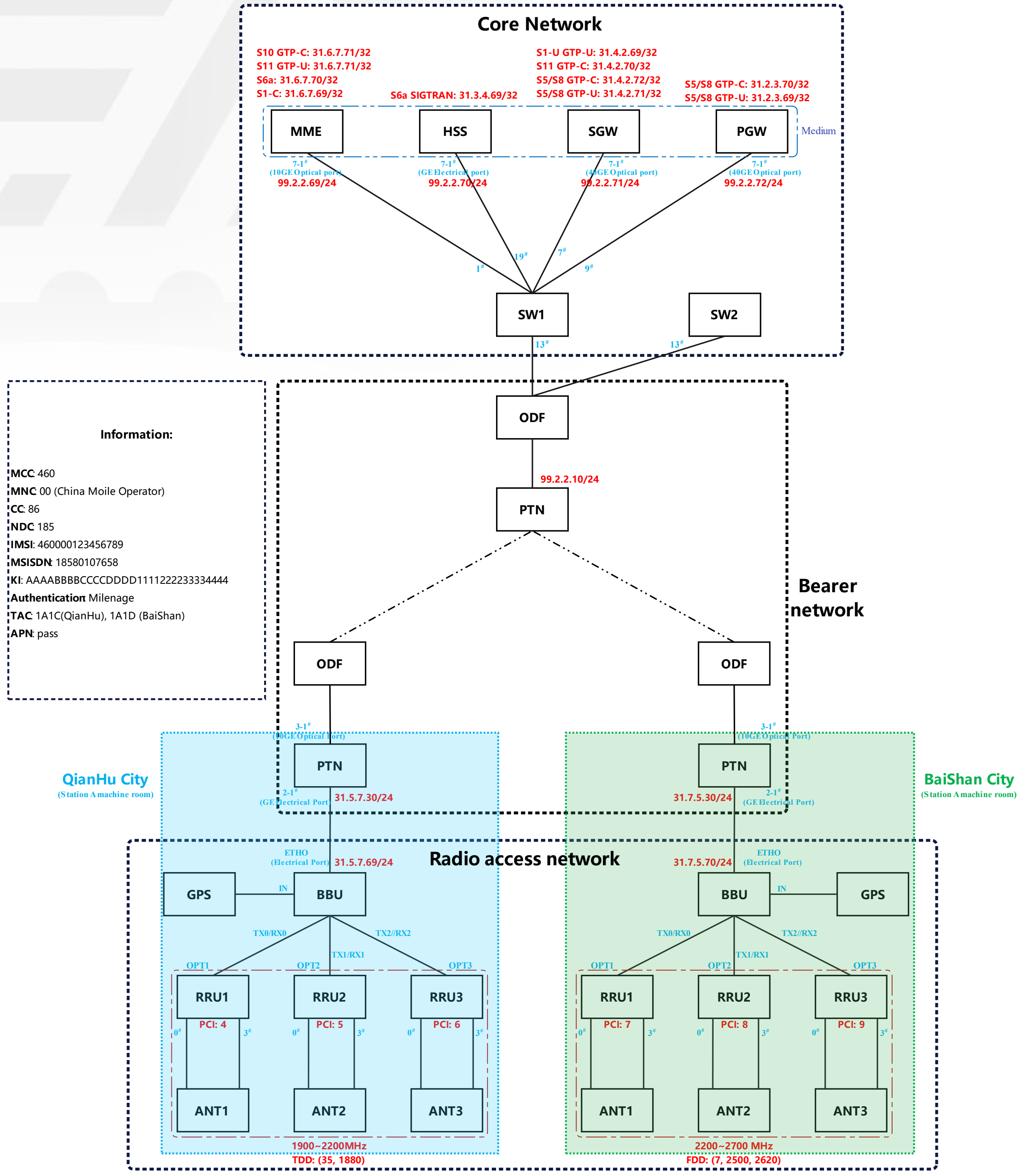

Figure 1 Network extension planning diagram for QianHu and BaiShan

Figure 1 shows the corresponding network extension planning. Since BaiShan City does not have its own core network, both QianHu City and BaiShan City use QianHu City's core network. Figure 2 shows the detail information for data configuration of RANs.

RANs in each city

City	eNode Instr	Mode	MCC	MNC	RRU Frequency band		Cell ID	TAC	PCI	Frequency Band	Center carrier frequency	Bandwidth	Subframe allocation	Subframe configuration	Antenna	Mode	MCS	RB	CFI	Power
WanLv	1	TDD	460	01	1700~1900MHz	Cell 1	1	1A1B	1	35	1880	20	2/3	7	2	TM3	1	100	1	15.2
						Cell 2	2	1A1B	2	35	1880	20	2/3	7	2	TM3	1	100	1	15.2
						Cell 3	3	1A1B	3	35	1880	20	2/3	7	2	TM3	1	100	1	15.2

City	eNode Instr	Mode	MCC	MNC	RRU Frequency band		Cell ID	TAC	PCI	Frequency Band	Center carrier frequency	Bandwidth	Subframe allocation	Subframe configuration	Antenna	Mode	MCS	RB	CFI	Power
QianHu	2	TDD	460	00	1900~2200MHz	Cell 1	4	1A1C	4	33	1910	20	2/3	7	2	TM3	1	100	1	15.2
						Cell 2	5	1A1C	5	33	1910	20	2/3	7	2	TM3	1	100	1	15.2
						Cell 3	6	1A1C	6	33	1910	20	2/3	7	2	TM3	1	100	1	15.2

City	eNode Instr	Mode	MCC	MNC	RRU Frequency band		Cell ID	TAC	PCI	Frequency Band	Bandwidth	Up carrier frequency	Down carrier frequency	Antenna	Mode	MCS	RB	CFI	Power
BaiShan	3	FDD	460	00	2200~2700MHz	Cell 1	7	1A1D	7	7	20	2500	2620	2	TM3	1	100	1	15.2
						Cell 2	8	1A1D	8	7	20	2500	2620	2	TM3	1	100	1	15.2
						Cell 3	9	1A1D	9	7	20	2500	2620	2	TM3	1	100	1	15.2

Figure 2 Data set for RANs

2. Complete network topology diagrams

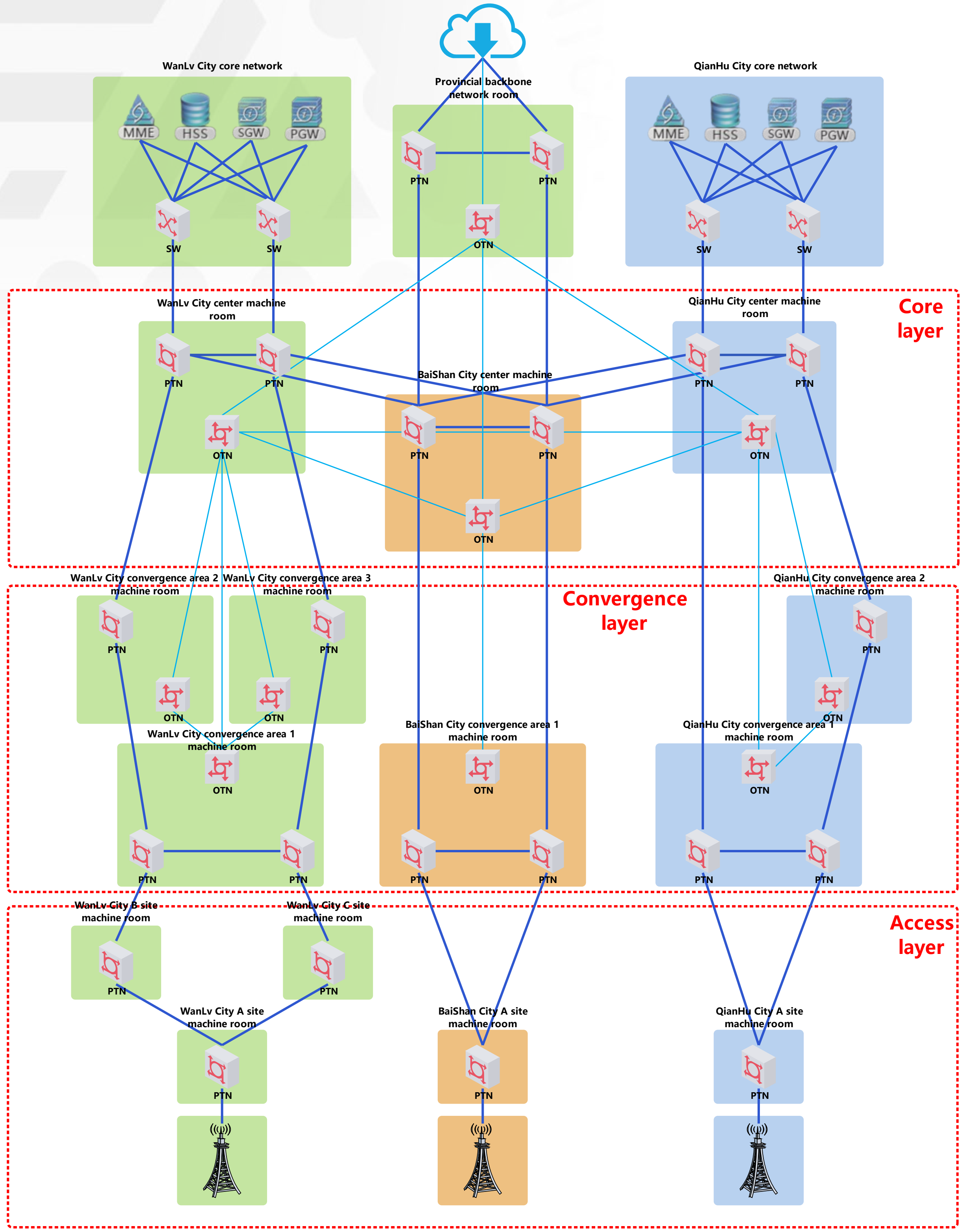

Figure 3 Network Topology Diagram for the completed experiments

3. Capacity Planning

3.1 RANs

Table 1 Capacity Planning of RANs

Radio Access Network RANs		WanLv City WanLv Planning	QianHu City QianHu Planning	BaiShan City BaiShan Planning
Capacity estimation	Average busy hour service throughput of a single user (kbps)	157.15	136.36	129.43
	The total number of 4G users in the city (10000)	60	28	12
	Total throughput of the city's planned area (Mbps)	92080.08	37285.94	15167.58
	Capacity Indicates the number of sites	205	119	49
Coverage estimation	Local station selection	65 degree orientation station	90 degree orientation station	Omnidirectional station
	Single station coverage area (km^2)	0.31	0.7	2.03
	Overwrite the estimated number of sites	1742	858	286
Conclusions	Number of local stations	1742	858	286
	Average throughput per station (Mbps)	52.86	43.46	53.03

Table 1 shows the capacity planning of RANs. Firstly, regarding the selection of **city models**, WanLv is a modern city with a large population, making Model A the appropriate choice. The population and urban scale of QianHu and BaiShan are progressively smaller. Therefore, Models C and E are selected for these cities, respectively.

In terms of coverage estimation, the available types of base stations include omnidirectional, three-sector 65-degree orientation, and three-sector 90-degree orientation stations. The omnidirectional station has the widest coverage radius but the lowest system user capacity, while the three-sector 65-degree orientation station offers the smallest coverage radius but the highest user capacity. The three-sector 90-degree orientation station provides a balance between coverage radius and user capacity. Given WanLv City's large and densely populated characteristics, the three-sector 65-degree orientation station was selected. For QianHu and BaiShan, which are progressively smaller in scale, the 90-degree and omnidirectional stations were chosen, respectively.

In summary, WanLv City has the highest number of users and the greatest throughput demand, necessitating the highest number of sites and the densest site distribution. QianHu City, with fewer users and a lower throughput demand than WanLv, has a moderate number and density of sites. BaiShan City, with the lowest demand for users and throughput, has the fewest stations; however, each station covers a larger area, resulting in a higher load per station.

3.2 Core Networks (CN’s)

Table 2 Traffic Model Planning

Traffic Model Planning

Parameter		Planned Value		
		WanLv City	QianHu City	BaiShan City
Core Network		WanLv Planning	QianHu Planning	BaiShan Planning
Online user ratio		0.9	0.8	0.7
Attach Activation Ratio		0.5	0.5	0.5
Average busy hour signaling flow per user (kbps)	S1-MME	10	8	5
	S11	3	2	1
	S6a	7	5	3
Busy Hour Average Service Throughput per User(kbps)		157.15	136.36	129.43
Total Number of 4G Users (in ten thousand)		60	28	12

$$\text{Online user ratio} = \frac{\text{Number of online users}}{\text{Number of accessible users}}$$

$$\text{Attach Activation Ratio} = \frac{\text{The number of successfully activated attachments}}{\text{Total number of attachment requests}}$$

The "Busy hour average service throughput per user" and "Total number of 4G users" are synchronized with the Radio Access Networks (RANs). In contrast, "Online user ratio," "Attach activation ratio," and "Average busy hour signaling flow per user" are manually configured.

Given that the urban scale of WanLv, QianHu, and BaiShan decreases sequentially, the data for WanLv City is set higher, while the data for BaiShan City is set lower. This descending configuration approach enables effective control over network resource investment and minimizes unnecessary waste, while still meeting the needs of users in each city. Overall, this method of configuring parameters according to city size and demand not only ensures service quality but also achieves economic efficiency. Table 3 shows the data planning of core network plan.

Table 3 Core network data planning report

Core Network		WanLv City WanLv Planning	QianHu City QianHu Planning	BaiShan City BaiShan Planning	QianHu+BaiShan Q+B Planning
MME	SAU (ten thousand)	54	25.2	10.8	36
	System Signaling Throughput (Gbps)	10.29	3.6	1.54	5.14
SGW	EPS Bearer Throughput (ten thousand)	108	50.4	21.6	72
	System Processing Capacity (Gbps)	83.67	32.77	13.33	46.1
	System Throughput (Gbps)	90.97	36.83	14.98	51.81
PGW	EPS Bearer Throughput (ten thousand)	108	50.4	21.6	72
	System Processing Capacity (Gbps	80.93	32.77	13.33	46.1
	System Throughput (Gbps)	88.06	86.6	14.5	101.1

IV. Several Questions

a. Types of roaming, process, their advantages and disadvantages

In the mobile communication system, the data transmission of roaming users is mainly realized by two ways: Home routing (HR) and Local Breakout (LBO) [1].

(1) **Home routed (HR):** In the HR mode, the user's PDU session is managed by the Session Management Function (SMF) of the home network. User data is transmitted from the access network to the home network, and then further routed to the target data network via the home network.

Advantages: The HR mode is widely adopted by mobile operators for data roaming. One primary reason for this preference is its ability to reduce disputes regarding traffic handling, as both the user and control plane traffic are routed through the visited-SGW and home-PGW. This allows for straightforward validation of usage and billing records, which is crucial in inter-operator financial settlements.

Disadvantages: Firstly, both the home and visited operators incur significant costs due to the need for interconnect hubs, leading to elevated data roaming tariffs. This high cost often deters users from utilizing data roaming services. Secondly, as traffic traverses multiple network hops before reaching its destination, achieving the low latency typically expected in a genuine 4G experience becomes challenging.

(2) **Local breakout (LBO)**: In the LBO mode, the user's PDU session is controlled by the SMF of the access network. User data is directly routed to the local data network within the access network without being transmitted back to the home network.

Advantages: The LBO scenario addresses many of the limitations associated with HR. Specifically, as the user plane traffic is handled entirely within the network visited using its SGW and PGW, it eliminates the need for routing traffic to the home network. This results in lower latency and improved efficiency.

Disadvantages: The primary drawback of the LBO mode is the home operator's inability to independently verify the monthly interconnection bills (Call Detail Records, or CDRs) provided by the operator visited. This creates challenges in billing validation and reconciliation. Furthermore, the home operator is required to bill the customer while simultaneously paying the charges to the visited operator, potentially introducing risks in financial management and accuracy.

b. Determined the slot number for the SRS (Sounding Reference Signal) in 5G OPTION 3X

A sounding reference signal (SRS) is a physical signal sent by user equipment (UE) to the base station over the uplink to estimate the quality of the uplink channel [2]. The base station uses the SRS to: Calculate a user's uplink channel, Allocate radio resources to the UE, and Support downlink beamforming [3].

Since the experiment selected $\mu = 1$, means $\Delta f = 2^{\mu} \times 15kHz = 30kHz$. The length of a signal symbol is $\frac{1}{f} = 33.3\ us$, the length of a CP is $2.4\ us$ [4], and there are 14 such combinations in a time slot (CP+symbol). Therefore, the length of a time slot is $35.7 \times 14 = 0.499ms \approx 0.5ms$, a signal subframe has 5 time slots, therefore, the length of Single-cycle 5GNR frame is 2.5ms.

Slot Position	0	1	2	3	4	5	6	7	8	9
Slot structure	D	D	D	S	U	D	D	D	S	U

Figure 4 2.5ms Single-cycle 5GNR Common frame structure configuration

Figure 4 shows the 2.5ms 5GNR frame structure configuration, where 'D' means downlink time slot, 'U' means uplink time slot, 'S' means special time slot. The SRS must be placed in the uplink timeslot (U) because this is when the user signals the base station. The SRS slot number is related to the number of the first uplink slot configured in the system. In Figure 4, slot number is calculated from 0. Slot number 4 is the first uplink slot, so the slot number of **SRS is set to 4**.

c. PCI planning methods

PCI, or Physical Cell Identity, is a crucial parameter within LTE (Long-Term Evolution) and 5G cellular networks. Serving as a unique identifier, PCI is assigned to each cell in the network, enabling clear differentiation and distinction between neighboring cells. This identification is essential for efficient network operation, as it facilitates seamless handovers, interference management, and optimized resource allocation across the cellular infrastructure [5].

In terms of LTE/LTE-A network, Physical Cell ID (PCI) is used to identify a network cell at the physical layer and typically involves 504 unique values. These values are represented by a combination of primary synchronization signals (PSS) and secondary synchronization signals (SSS) [6]. The SSS (or PCI-group) consists of 168 sequence numbers: $N_{ID}^{(1)} = [0, 167]$, and the PSS (or PCI-ID) consists of 3 different sequence numbers: $N_{ID}^{(2)} = [0, 2]$. A PCI is defined as [7]:

$$N_{ID}^{(cell)} = 3 \times N_{ID}^{(1)} + N_{ID}^{(2)}$$

Which gives the maximum PCI value 503 when $N_{ID}^{(1)} = 167\ and\ N_{ID}^{(2)} = 2$ and the minimum value 0 for $N_{ID}^{(1)} = N_{ID}^{(2)} = 0$.

In the IUV-Pre 4G or IUV-5G software, each cell should be assigned to a different PCI.

d. RRU radio frequency configuration

When configuring radio frequencies for RRUs, it is feasible to assign distinct frequency bands to each of the three RRUs.

In contemporary wireless communication systems, RRUs are generally equipped with multi-band support capabilities, enabling efficient allocation of spectrum resources tailored to the requirements of varying regions and operational scenarios. Configuring different RRUs to operate on different frequency bands optimizes spectrum utilization, enhancing overall network performance in diverse environments.

Moreover, if the three RRUs are deployed within the same geographical location, utilizing separate frequency bands for each unit can mitigate self-interference issues. By operating across distinct frequency channels, RRUs effectively reduce co-channel interference, which is critical for maintaining network stability and minimizing mutual interference between frequency bands.

e. The meaning of TAC and the method to divide TAC

In mobile communication networks, the Tracking Area Code (TAC) serves as a unique numerical identifier for a specific Tracking Area (TA), which comprises multiple cells. The TAC facilitates the differentiation between distinct TAs within the network. In both LTE (Long-Term Evolution) and 5G architectures, the TAC forms part of the broader

Tracking Area Identity (TAI), which includes the Mobile Country Code (MCC), Mobile Network Code (MNC), and the TAC itself. Each TA may encompass one or more cells, although each cell is exclusively assigned to a single TA. Figure 5 shows the TAC configuration.

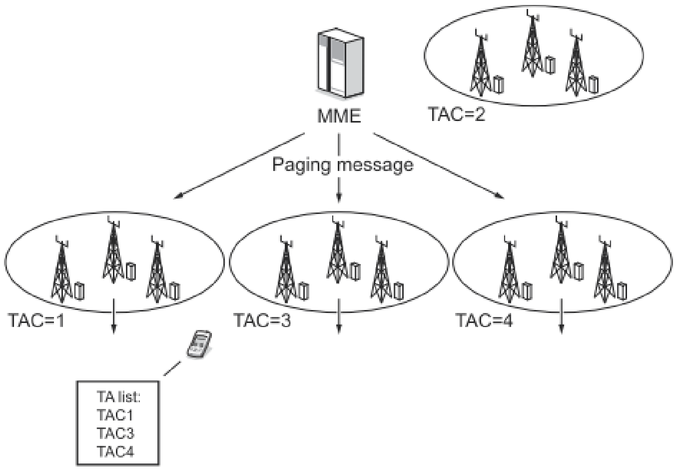

Figure 5 TAC and TAC list [8]

The Tracking Area Code (TAC), represented as 4 hexadecimal value, is a parameter defined within the Mobility Management Entity (MME) of the core network. The MME plays a critical role in managing user mobility by associating specific tracking areas with each eNodeB. This tracking area information enables the MME to efficiently page idle User Equipment (UE), facilitating the notification process for incoming data connections. Such configurations are essential for ensuring seamless connectivity and mobility management within the network [8].

f. Configure the GP, upstream symbol count, and downstream symbol count of the S slot in DU cell service parameters

Unlike LTE, 5G NR uses a more flexible frame structure. Figure 6 shows the frame architecture of 5G NR.

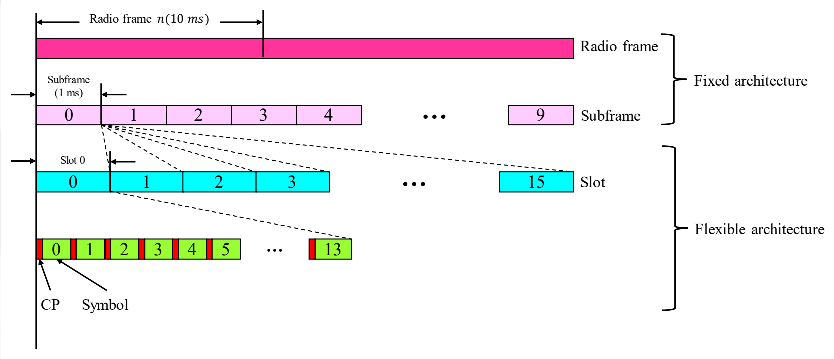

Figure 6 5G frame structure schematic

According to 3GPP, each subframe can correspond to multiple time slots, and the length of time slots depends on μ, and the value of u can range from 1 to 4 [9]. Figure 7 shows the slot number corresponding to μ.

μ	N_{symb}^{slot}	$N_{slot}^{frame,\mu}$	$N_{slot}^{subframe,\mu}$
0	14	10	1
1	14	20	2
2	14	40	4
3	14	80	8
4	14	160	16

Figure 7 Number of OFDM symbols per slot, slots per frame, and slots per subframe for normal cyclic prefix [9]

In 5G, the classification of an OFDM symbol within a time slot can be categorized as "downlink" (denoted by D), "special" (denoted by S), or "uplink" (denoted by U). The uplink and downlink transmissions are configured using the OFDM symbol as the smallest unit. However, with the exception of "full uplink" and "full downlink" configurations, all other scenarios must include at least one "special" (S) symbol [10]. In 5G NR, the frame structure employs a range of slot configurations with adjustable ratios. The allocation of downlink symbols, Guard Period (GP), and uplink symbols within special time slots is flexible. Xiao suggests that the GP should span 2-4 OFDM symbol durations, proposing a D:GP:U ratio of 10:2:2 [11].

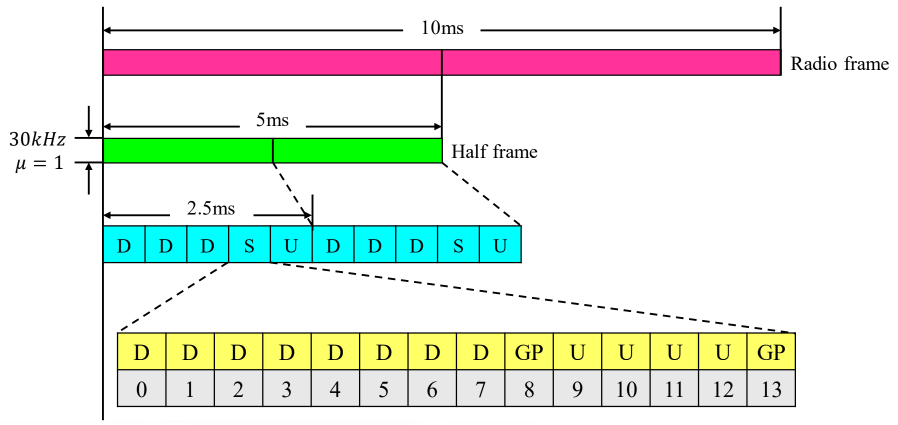

Figure 8 S slot configuration in 2.5ms signal period

To ensure a total of 14 symbols comprising D, GP, and U, while maintaining a higher number of downlink symbols than uplink symbols, the IUV-5G experiment is configured with **2 symbols allocated to GP, 4 symbols to uplink, and 8 symbols to downlink**. Figure 8 shows the S slot configuration and the corresponding allocation sequences.

g. The reasons for user authentication failure

Authentication is the process of verifying a user's identity within a communication system, serving primarily to confirm that the User Equipment (UE) holds legitimate access rights and to prevent unauthorized access to the network. In the context of LTE/5G NSA, the Home Subscriber Server (HSS) plays a critical role, managing user contract information and overseeing user location data. This function is fundamental in ensuring secure access control and maintaining the integrity of network resources [12].

Therefore, authentication is an interactive process between the HSS and the user. The primary cause of user authentication failure is a mismatch between the keys stored in the user device (UE) and those maintained in the core network's HSS. These keys are typically derived from subscriber information, such as the IMSI, and an encryption algorithm; any invalid key or synchronization error will disrupt the authentication process. A secondary cause of failure arises from inconsistencies between the IMSI and HSS configurations. Subscription information, including the IMSI, is stored in the HSS, and if this information is incomplete, invalid, or misaligned with the UE data, authentication will similarly fail.

h. Configuring basic session services in the MME

(1) APN address resolution

APN (Access Point name) is used to identify the external data network to which the user wishes to connect. When a user device (UE) initiates an attachment or session establishment request, the MME queries the PGW (Packet Data Gateway) address based on the APN name.

Since APN address resolution is addressed to PGW, the resolution address is the S5/S8 address of PGW of the local core network.

(2) EPC address resolution

EPC (Evolved Packet Core Network) address resolution is mainly used to determine the address of SGW (Service Gateway). When the UE is attached to the network, the MME needs to select an appropriate SGW for it.

The EPC address resolves the interface address of SGW and MME, that is, the S11 GTP-C address of SGW.

(3) TA resolution

TA address resolution involves MME selection in different scenarios. For example, when a UE moves between different MME, the MME needs to select the target MME based on the TA information.

TA resolution is used in the switchover process to resolve the MME

S10 GTP-C address of the peer core network.

i. The reasons that cause a cell to switch in only one direction

In the IUV-Pre 5G software, QianHu and BaiShan cities share the same core network (the QianHu core network). Consequently, when switching between WanLv and other cities, core network reconfiguration is required, whereas transitions between QianHu and BaiShan cities necessitate only RAN configuration adjustments.

Unidirectional cell handovers typically arise due to two primary causes: incorrect core network address configurations or inconsistencies in the RAN configuration relative to other urban access networks. For the core network configuration, successful handover requires accurate settings for MME address resolution, TA address resolution, and the addition of static routes. Since a default route is employed, static route configuration errors are not a concern. It is essential to verify whether the MNC in both the MME and TA address resolutions corresponds to that of the target core network and whether address resolution settings are correct. Additionally, in the TA analysis configuration, WanLv City must account for the TACs of both QianHu and BaiShan Cities, necessitating the inclusion of two TA analyses.

The main challenge, however, lies in the RAN data configuration. When configuring adjacent cells, it is critical to verify parameters such as the eNBID, MCC, MNC, TAC, PCI, band indication, bandwidth, and center carrier frequency of the adjacent cell. Furthermore, ensure the adjacency table configuration is correctly verified.

j. The principles of control plane and user plane in 5G NSA mode

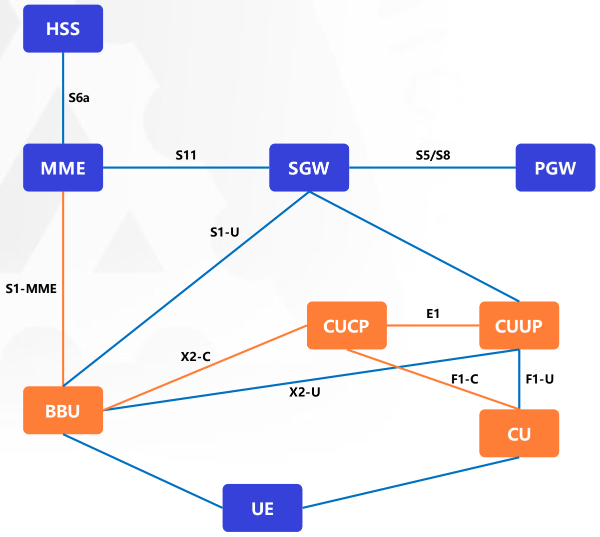

Figure 9 5G NSA OPTION 3X network architecture

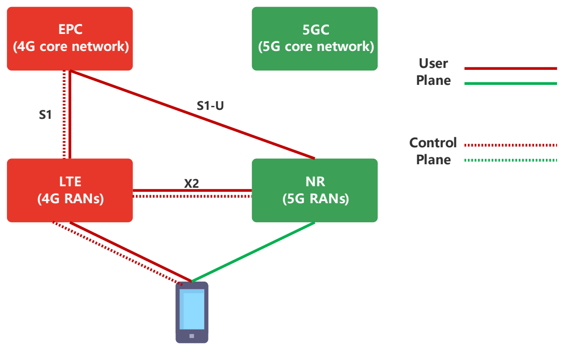

Figure 10 OPTION 3X non-independent network

Figure 9 and Figure 10 shows the network architecture of 5G NSA mode, where orange lines mean control flow and blue lines mean signal flow. The NSA approach retained the core architecture of the LTE system, while advancing the 5G RAN through Option 3. This configuration integrates the evolving 5G gNB with the existing LTE EPC, allowing for a smooth transition and interoperability between the two generations of mobile network technology [13].

a) **Control plane**: In the Option 3X architecture, the control plane is managed by the LTE network, specifically through the eNodeB (eNB). Initially, the UE connects to the LTE network, where all signaling and control data are relayed to the EPC via the eNB. Consequently, control functions, including connection management and mobility management for the UE, are effectively overseen by the LTE network, ensuring seamless coordination and continuity.

b) **User plane**: User data can be transmitted between the eNB and gNB, allowing simultaneous data transmission over LTE and 5G NR to enhance overall throughput and user experience. At the PDCP layer in the gNB, data is split: part is sent directly through the gNB, while the remainder is routed to the eNB via the X2 interface, which then transmits it to the UE. In addition, communication between the eNB and gNB occurs over the X2 interface, which includes both a user plane (X2-U) for data transfer and a control plane (X2-C) for control signaling.

V. **Main Issues Encountered in the Experimental Course and Their Solutions (30 points)**

(1) S1-MME link interface fault, BBU S1-C link fault:

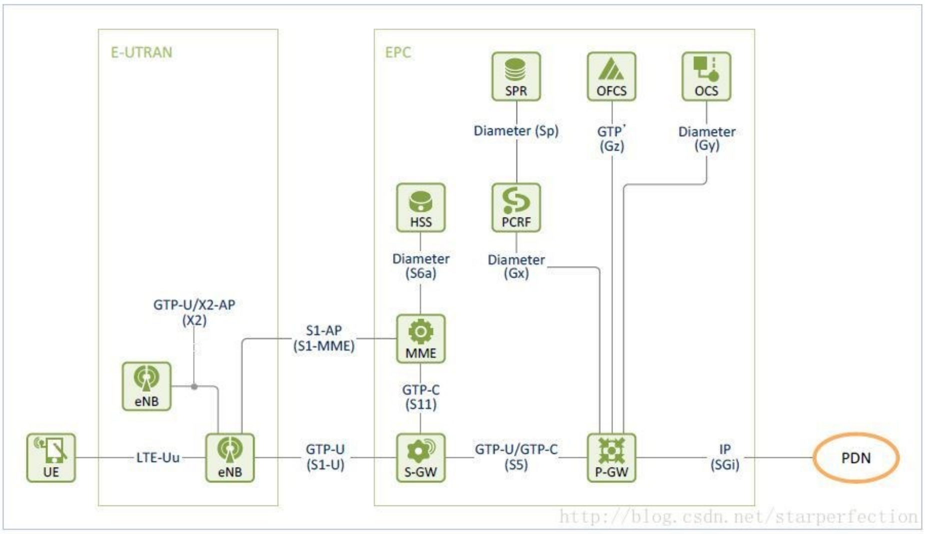

Figure 11 LTE network architecture

As shown in Figure 11, S1-MME connect eNB and MME. I reviewed the interconnection configuration between the MME and the eNB and confirmed the accuracy of the data. Subsequently, I examined the BBU of the RANs and discovered that the remote IP address in the SCTP configuration of the BBU was incorrect. Since the S1-MME interface is responsible for transmitting control information, the issue is traced to a failure in the SCTP configuration.

(2) BBU connection failure in QianHu city: Description An incorrect bearer link port is found in the physical parameter of BBU.

(3) The interfaces of multiple Nes (network elements) on the core network are faulty: I verified the global mobility parameters in the MME and the PLMN connections in the SGW and PGW, with no errors detected. However, upon reviewing the IP address configuration, I identified that the subnet mask was mistakenly set to 32 bits instead of the required 24 bits. This additional check, beyond the routing addresses, was necessary due to the high frequency of simultaneous faults, suggesting that the issue was more likely related to misconfigurations in certain interface or global addresses rather than a simple routing IP mismatch.

(4) No alarm is generated, the network connection is down, and the service observation indicates that PGW cannot be found: MME- Basic session service configuration - The APN resolution address is incorrectly configured. For instance, I wrote "test" in the APN as "tset".

(5) No relevant SGW could be found: MME- Basic session Service configuration - The EPC parsing configuration is incorrect.

(6) Service observation displays "Data transmission Interrupted": The transmission process of user data plane is from terminal to BBU, to SGW and then to PGW, as shown in Figure 12.

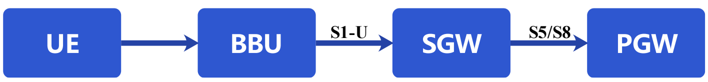

Figure 12 User data transmission process

In MME: Verify the interconnection configuration with eNodeB, including IP address and TA data, and ensure the MME control plane address in connection with SGW is correct. Check routes to QianHu and BaiShan base stations and to SGW.

In SGW: Confirm that the IP addresses for interconnection with MME and PGW are correct.

In PGW: Ensure the IP address for interconnection with SGW is accurate.

(7) User authentication fails: This issue arises due to a mismatch between the KI or IMSI of the terminal information and the HSS in the core network. For instance, KI of HSS is 11112222333344444AAAABBBB CCCCDDDD, but KI of terminal information is AAAABBBBCCCCDDDD D1111222233334444.

(8) Roaming failure: Roaming is to configure the interconnection between MME of WanLv City and HSS of QianHu City, and the interconnection between MME of QianHu City and HSS of WanLv City. Figure 13 shows the process.

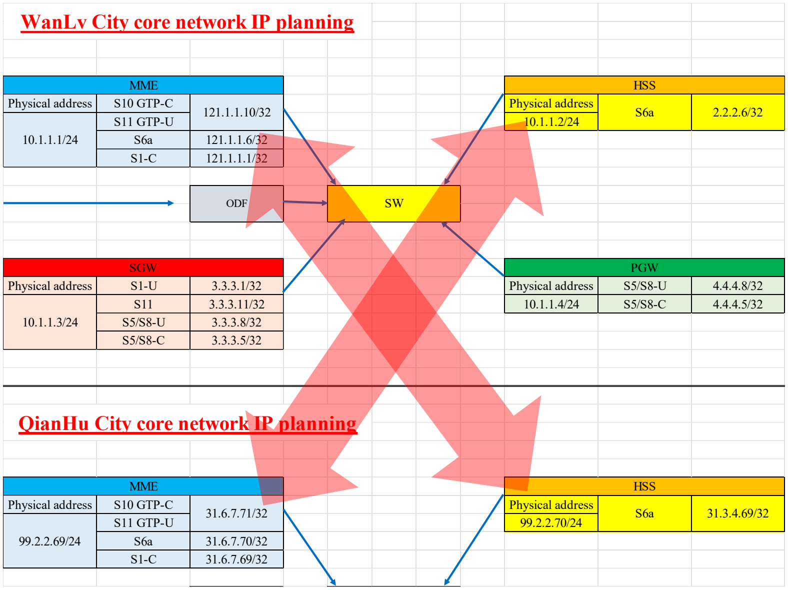

Figure 13 Roaming

After checking, it was found that the IP port number in the Diameter connection added for roaming does not correspond to the other core network

(9) In IUV-5G software, DU cell unavailable: This suggests an issue with the DU cell configuration within the RAN, as only one of the three sectors reported an error, indicating that global parameters are likely correct. Upon inspection, it was found that the radio frequency configuration for AAU3 had been overlooked.

(10) DU cell unavailable: It is the same mistake. After reviewing the sector

carrier parameters, DU cell configuration, admission control settings, BWPUL, and BWPDL, it was identified that the Downlink Point A frequency in the DU cell configuration is incorrectly set.

(11) The 5G network is unavailable: In the OPTION 3X network, control flow is transmitted over the LTE network, while data flow is transmitted via 5G NR. Consequently, checking the BBU data configuration is essential. Upon examining the NR neighbor cell configuration and adjacency relation table in the BBU, I discovered that the neighboring DU identifier for my BBU was incorrectly configured.

(12) Network mode error: The clock synchronization modes of the BBU and ITBBU are inconsistent. In this experiment, the "phase synchronization" mode should be selected.

(13) X2 link failure - No 5G signal: As shown in Figure 9, the control plane uses X2 to connect the BBU and CUCP, while on the user side, X2 connects the BBU to the CUUP. This makes it essential to verify the SCTP configuration for the BBU, CUCP, CUUP, and the static route settings. Upon inspection, I found that the SCTP configuration for the connection between the BBU and CUCP was set to NG coupling, whereas it should have been configured as XN coupling. Figure 14 summarizes my SCTP configuration data.

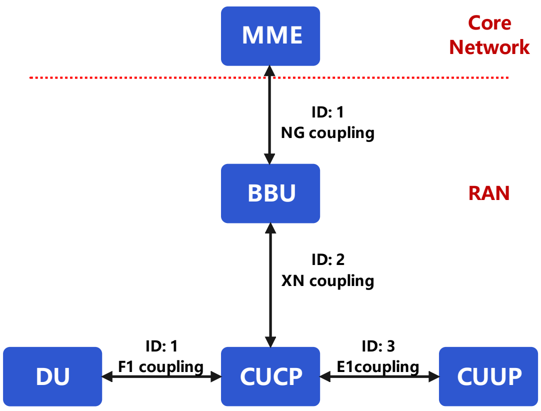

Figure 14 SCTP interconnects configuration

VI. Conclusions (5 marks)

This study examined the configurations of LTE and 5G networks, with an emphasis on topology and capacity planning tailored to the unique demands of WanLv, QianHu, and BaiShan cities. Selecting base station models optimized for each location achieved a balance between coverage and user capacity. The findings highlight the crucial role of accurate configurations of Physical Cell Identity (PCI), radio frequency settings, and Tracking Area Code (TAC) for optimal performance. The integration of LTE and 5G, especially in NSA mode, revealed the complexity of session management and seamless connectivity. These results underscore the importance of precise parameter adjustments to meet diverse network demands. Future research may focus on automated configuration and fault detection solutions, which are essential for managing the increasing complexity of next-generation networks.

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