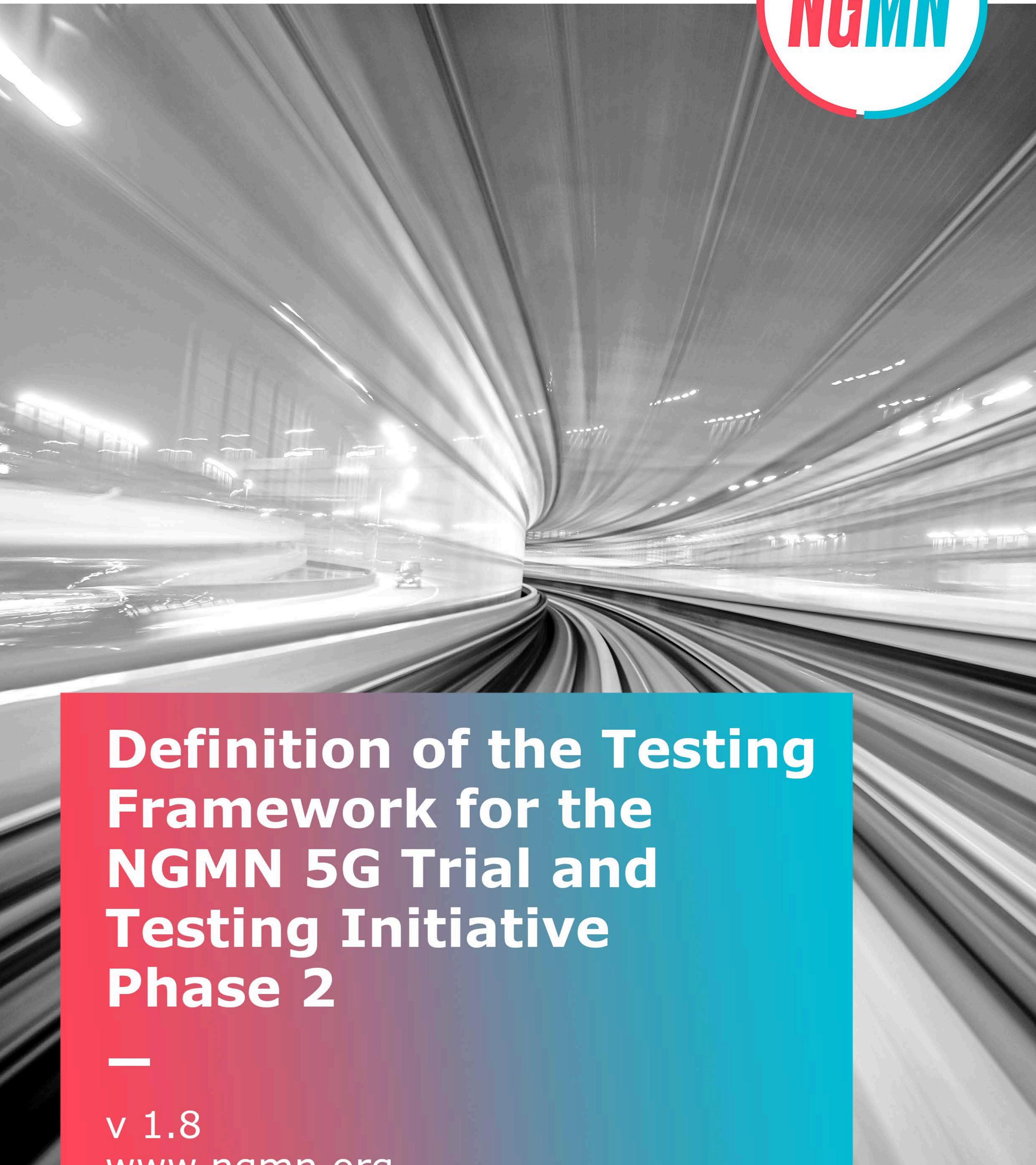

Definition of the Testing Framework for the NGMN 5G Trial and Testing Initiative Phase 2

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DEFINITION OF THE TESTING FRAMEWORK FOR NGMN 5G TRIAL AND TESTING INITIATIVE PHASE 2

by NGMN Alliance

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Abstract

NGMN started its 5G Trial & Testing Initiative (TTI) Phase 2 in 2021 to continue the global collaboration on test activities towards the commercialisation of 3GPP Releases 16/17/18. This White Paper focuses on the definition of the testing framework for Release 16, including the test configurations, the working scope, the trial setup requirements, and the testing methodologies. The scope of testing covers four technology categories: Smart and Effective System, Enhancement of Existing Capabilities, Maximising Spectrum Value, and New Application Enabler. Each category consists of several technology directions, which are broken down to the technology features highlighted from the global operators' perspective. The corresponding test results will be published in future NGMN deliverables.

Contents

1 INTRODUCTION

This White Paper is the first of six deliverables of NGMN's 5G Trial and Testing Initiative (TTI) Phase 2. Phase 2 has the following objectives:

- Enable the global collaboration of testing activities to support an efficient, successful, and in-time 5G technology and service introduction.
- Proof of Concept (PoC): Demonstrate the proof of concepts on the 5G functionality and performance of pre-standards (Release 17/18) technologies.
- Pre-commercial Trials: Visualise 5G capabilities and advantages in (nearly) pre-commercial conditions (Release 16/17/18).
- Consolidate contributions and report on the industry progress in order to ensure the development of globally aligned 5G technology and service solutions.
- Identify, test, and promote new business opportunities and use cases with industry stakeholders (e.g. from vertical industries).
- Provide NGMN's contributions to 3GPP Release 16/17/18 standards.

The milestones of Phase 2 are illustrated in **Error! Reference source not found.**. The current m ilestone is D1.

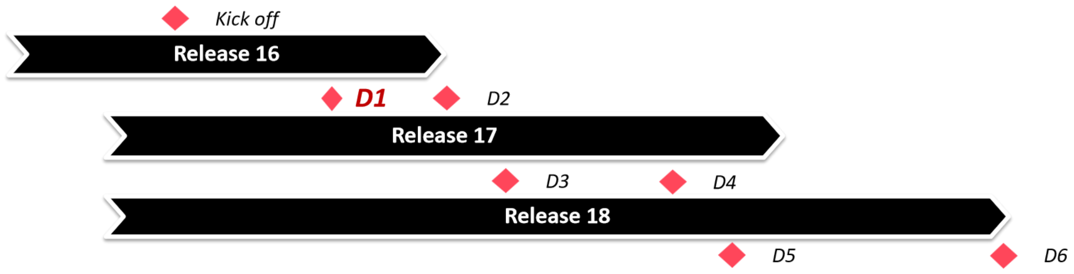


Figure 1: NGMN TTI Phase 2 Milestones

Notes:

- D1 – The framework definition for R16/Implementation schemes/Prototypes (this White Paper).
- D2 - Test results for R16/Implementation schemes/Prototypes.

- D3 - The framework definition for R17/Implementation schemes/Prototypes.
- D4 - Test results for R17/Implementation schemes/Prototypes.
- D5 - The framework definition for R18/Implementation schemes/Prototypes.
- D6 - Test results for R18/Implementation schemes/Prototypes.

2 SCOPE

NGMN 5G TTI Phase 2 includes the following four technology categories and key directions.

Table 1: NGMN 5G TTI Phase 2 Working Scope

Technology Categories	Key Directions	Releases
Smart and Effective System	AI	R16
	Base Station Energy Saving	R16
Enhancement of Existing Capabilities	Uplink Centric Evolution	R16
	Massive MIMO Evolution	R16
	URLLC Enhancement	R16
	Mobility Enhancement	R16
Maximising Spectrum Value	Duplex Evolution	R18
	Flexible Spectrum Access	R18 and beyond
	Multi-Band Serving-Cell	R18 and beyond
	Higher Frequency	R16
New Application Enabler	Positioning and Sensing Evolution	R16/R18 and beyond
	Passive IoT	R18 and beyond
	New Broadcasting Evolution	R17
	High-Interactive Broadband Communication	R17

Notes:

- The working scope may change with the project members' plans and the project progress.
- The technologies to be tested can be based on 3GPP specifications or vendor specific implementation schemes or prototypes.

- The Release version in Table 1 indicates the public release time of the first document corresponding to that of each 3GPP standards. The document can be implementation schemes, prototypes, protocols, etc., of each key direction.

3 TRIAL SETUP REQUIREMENTS

This chapter specifies the deployment scenarios including the used frequency bands and all the practical considerations for each deployment scenario [1]. For the detailed deployment requirements of each testing case, please refer to the Testing Configuration in Chapters 4-7. In case of the difference between the testing configuration and the deployment attributes and values in this chapter, please refer to the configuration requirements in Chapters 4-7.

3.1 Indoor Hot Spot

This section focuses on the high user density and the high capacity/throughput in the indoor hot spot scenario. Scenario specific deployment attributes and expected values are listed in Table 2.

Table 2: The Deployment Attributes of the Indoor Hot Spot Scenario

Attributes	Expected Values
Carrier Frequency	Sub 6 GHz and above 6 GHz (around 30 GHz & 70 GHz)
Aggregated System Bandwidth	Sub 6 GHz: 100 MHz Above 6 GHz (around 30 GHz & 70 GHz): 800 MHz
Sub-Carrier Spacing	eMBB: 30 kHz for sub 6 GHz, 120 kHz for above 6 GHz URLLC: 60 (30) kHz
Carrier Prefix (CP) Length	2.3 us for eMBB; 1.2 us for URLLC
Slot Length	eMBB: 0.5 ms (14 symbols), 0.25 ms (7 symbols) (Optional: mini-slots) URLLC: 0.125 ms
Number of Layers	1
BS Antenna Elements	Sub 6 GHz: up to 256 Tx and Rx antenna elements (64 or 128 is recommended)

	Above 6 GHz: up to 256 Tx and Rx antenna elements (around 30 GHz & 70 GHz)
UE Antenna Elements	Sub 6 GHz: up to 8 Tx and Rx antenna elements (4 is recommended) Above 6 GHz: up to 32 Tx and Rx antenna elements (around 30 GHz & 70 GHz)
User Location and Speed	100% indoor (3 km/h)
Traffic Type	The full buffer or non-full-buffer traffic depends on the scenario
Inter Site Distance	20 metres

3.2 Dense Urban

This section focuses on the high user density and high traffic loads in city centres in the outdoor and outdoor-to-indoor coverage scenarios. Scenario specific deployment attributes and expected values are listed in Table 3.

Table 3: The Deployment Attributes of the Dense Urban Areas

Attributes	Expected Values
Carrier Frequency	Sub 6 GHz and above 6 GHz (around 30 GHz)
Aggregated System Bandwidth	Sub 6 GHz: 100 MHz Above 6 GHz (around 30 GHz): 800 MHz
Sub-Carrier Spacing	eMBB: 30 kHz for sub 6 GHz, 120 kHz for above 6 GHz URLLC: 60 (30) kHz
Carrier Prefix (CP) Length	2.3 us for eMBB; 1.2 us for URLLC
Slot Length	eMBB: 0.5 ms (14 symbols), 0.25 ms (7 symbols) (Optional: mini-slots) URLLC: 0.125 ms
Number of Layers	2
BS Antenna Elements	Sub 6 GHz: up to 256 Tx and Rx antenna elements (64 or 128 is recommended) Above 6 GHz: up to 256 Tx and Rx antenna elements (around 30 GHz)
UE Antenna Elements	Sub 6 GHz: up to 8 Tx and Rx antenna elements (4 is recommended) Above 6 GHz: up to 32 Tx and Rx antenna elements (around 30 GHz)

User Location and Speed	80% indoor (3 km/h) and 20% outdoor (30 km/h)
Traffic Type	The full buffer or non-full-buffer traffic depends on the scenario
Inter Site Distance	200 metres

3.3 Urban Macro

This section focuses on the continuous coverage in the urban macro scenario. Scenario specific deployment attributes and expected values are listed in Table 4.

Table 4: The Deployment Attributes of the Urban Macro Scenario

Attributes	Expected Values
Carrier Frequency	Sub 6 GHz and above 6 GHz (around 30 GHz)
Aggregated System Bandwidth	Sub 6 GHz: 100 MHz Above 6 GHz (around 30 GHz): 800 MHz
Sub-Carrier Spacing	eMBB: 30 kHz for sub 6 GHz, 120 kHz for above 6 GHz URLLC: 60 (30) kHz
Carrier Prefix (CP) Length	2.3 us for eMBB; 1.2 us for URLLC
Slot Length	eMBB: 0.5 ms (14 symbols), 0.25 ms (7 symbols) (Optional: mini-slots) URLLC: 0.125 ms
Number of Layers	1
BS Antenna Elements	Sub 6 GHz: up to 256 Tx and Rx antenna elements (64 or 128 is recommended) Above 6 GHz: up to 256 Tx and Rx antenna elements (around 30 GHz)
UE Antenna Elements	Sub 6 GHz: up to 8 Tx and Rx antenna elements (4 is recommended) Above 6 GHz: up to 32 Tx and Rx antenna elements (around 30 GHz)
User Location and Speed	80% indoor (3 km/h) and 20% outdoor (30 km/h)
Traffic Type	The full buffer or non-full-buffer traffic depends on the scenario
Inter Site Distance	500 metres

3.4 Rural

This section focuses on the continuous coverage in the rural area. Scenario specific deployment attributes and expected values are listed in Table 5.

Table 5: The Deployment Attributes of the Rural Areas

Attributes	Expected Values
Carrier Frequency	Sub 6 GHz (around 4 GHz) and sub 1 GHz
Aggregated System Bandwidth	Sub 6 GHz: 100 MHz Sub 1 GHz: 20 MHz
Sub-Carrier Spacing	eMBB: 30 kHz for sub 6 GHz, 30 (15) kHz for sub 1 GHz URLLC: 60 (30) kHz
Carrier Prefix (CP) Length	2.3 us for eMBB; 1.2 us for URLLC
Slot Length	eMBB: 0.5 ms (14 symbols), 0.25 ms (7 symbols) (Optional: mini-slots) for sub 6 GHz; 0.5 ms for sub 1 GHz URLLC: 0.125 ms
Number of Layers	1
BS Antenna Elements	Sub 6 GHz: up to 256 Tx and Rx antenna elements (64 or 128 is recommended) Sub 1 GHz: up to 64 Tx and Rx antenna elements
UE Antenna Elements	Sub 6 GHz: up to 8 Tx and Rx antenna elements (4 is recommended) Sub 1 GHz: up to 4 Tx and Rx antenna elements
User Location and Speed	50% indoor (3 km/h) and 50% outdoor (30 km/h to 120 km/h)
Traffic Type	The full buffer or non-full-buffer traffic depends on the scenario
Inter Site Distance	1500 metres to 5000 metres

4 SMART AND EFFECTIVE SYSTEM

4.1 Artificial Intelligence (AI)

4.1.1 Radio-Fingerprint-Based Smart Handover

The UE handover highly depends on the measurement report (MR) of the cells on neighbour frequencies. With the increasing number of bands, inter-frequency/RAT (radio access technology) measurements of the UE may cause amounts of signalling overheads over the Uu interface, cost the massive UE power consumption, and severely impact running services due to the data interruption of the inter-frequency/RAT measurement gap. The inter-frequency/RAT measurements also lead to the slow handover as waiting for the inter-frequency/RAT MR from the UE. Therefore, how to enable the fast inter-frequency/RAT measurement for a more efficient handover becomes an important issue.

Based on the historical measurement results, the radio fingerprint information can be exploited and predicted, simultaneously with the great help for the multi-band inter-frequency/RAT handover. The radio fingerprint is composed of multiple virtual grids. The virtual grids are the logical units of one cell, and constructed based on historical reports of intra-frequency measurement results (including the reference signal received power [RSRP] of the serving cell and two neighbour cells with the strongest RSRP). The inter-frequency information stored in the grids is learned from the UE inter-frequency measurement reports. With the information of virtual grids, such as the cell ID for the inter-frequency/RAT handover and the DL spectrum efficiency (SE), the system can predict the RSRP, the interference, etc., of the target cell, as well as eliminate the handover measurement process to avoid the inter-frequency/RAT measurement gap and improve the efficiency of the inter-frequency/RAT handover.

4.1.1.1 Definition

For the radio-fingerprint-based smart handover, firstly, based on the intra-frequency measurement information of the UE, the inter-frequency/RAT measurement information of the UE is predicted by the radio fingerprint. Then the inter-frequency/RAT handover without the gap is performed. Its realisation involves the radio fingerprint construction, the radio fingerprint prediction, and the generation of the smart inter-frequency/RAT handover decision.

4.1.1.2 Testing Environment

4.1.1.2.1 Testing Setup

In the multi-band and multi-cell networking, the UE is randomly distributed.

Figure 2 illustrates an example. The test serving cell is CELL1, while CELL2 and CELL4 are the intra-frequency neighbour cells of CELL1. CELL3 is the inter-frequency neighbour cell of CELL1. CELL5 is a 4G neighbour cell of CELL1.

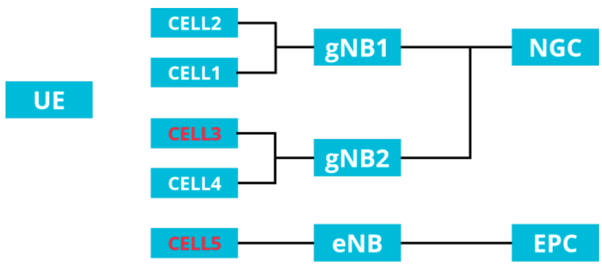


Figure 2: The Testing Setup for the Radio-Fingerprint-based Smart Handover

4.1.1.2.2 Testing Configuration

Table 6: The Testing Configuration for the Radio-Fingerprint-Based Smart Handover

Attributes	Expected Values
Carrier Frequency	Sub 6 GHz
Notes	1) The testing UE is registered and enters the RRC_IDLE state. 2) The UE resides in CELL1, a 5G cell, which has the intra-frequency 5G neighbours (CELL2 and CELL4), the inter-frequency 5G neighbour (CELL3), and the inter-RAT neighbour (CELL5). 3) The radio fingerprint of CELL1 has been constructed. 4) The testing UE supports the 4G frequency band of CELL5, the NR frequency band of CELL1, and the NR frequency band of CELL3.

4.1.1.2.3 Testing Procedures

1. The smart inter-frequency handover:
    1) Turn off the radio-fingerprint-based inter-frequency handover function.
    2) The testing UE initiates the service in CELL1 to enter the RRC_CONNECTED state.
    3) By adjusting the reference signal of CELL1, the UE is triggered to be handed over from CELL1 to CELL3 based on the UE inter-frequency MR.
    4) Repeat step 3) 10 times. Record the total time for the handover process (from the time when the serving cell initiates handover measurement configuration to the time when the target cell receives RRC connection reconfiguration completion) and the user throughput of UL and DL for each test.
    5) Turn on the radio-fingerprint-based inter-frequency handover function.
    6) The testing UE initiates the service in CELL1 to enter the RRC_CONNECTED state.
    7) By adjusting the reference signal of CELL1, the UE is triggered to be handed over from CELL1 to CELL3 based on the radio fingerprint through which the UE does not need the inter-frequency MR.

8) Repeat step 7) 10 times. Record the total time for the handover process (from the time when the serving cell initiates the RRC connection reconfiguration request to the time when the target cell receives the RRC connection reconfiguration completion) and the user throughput of UL and DL for each test.

2. The smart inter-RAT handover:
   1) Turn off the radio-fingerprint-based inter-RAT handover function.
   2) The testing UE initiates the service in CELL1 to enter the RRC_CONNECTED state.
   3) By adjusting the reference signal of CELL1, the UE is triggered to be handed over from CELL1 to CELL5 based on the UE inter-RAT measurement.
   4) Repeat step 3) 10 times. Record the total time for the handover process (from the time when the serving cell initiates handover measurement configuration to the time when the target cell receives RRC connection reconfiguration completion) and the user throughput of UL and DL for each test.
   5) Turn on the radio-fingerprint-based inter-RAT handover function.
   6) The testing UE initiates the service in CELL1 to enter the RRC_CONNECTED state.
   7) By adjusting the reference signal of CELL1, the UE is triggered to be handed over from CELL1 to CELL5 based on the radio fingerprint through which the UE does not need the inter-RAT measurement.
   8) Repeat step 7) 10 times. Record the total time for the handover process (from the time when the serving cell initiates the RRC connection reconfiguration request to the time when the target cell receives the RRC connection reconfiguration completion) and the user throughput of UL and DL for each test.

4.1.1.2.4 Success Criteria

1. After turning on the radio-fingerprint-based inter-frequency/RAT handover, the UE can successfully switch to the target cell without the inter-frequency/RAT measurement. Services continue.

2. After turning on the radio fingerprint-based inter-frequency/RAT handover switch, the handover execution is accelerated without the handover measurement, and the total time for the handover process is reduced.

3. After turning on the radio fingerprint-based inter-frequency/RAT handover switch, the UL and DL user throughput are significantly improved.

4.1.1.3 Reporting and Analysing Results

Table 7: The Reporting and Analysing Results for Radio-Fingerprint-Based Smart Handover

	Turn on the Handover Function	Turn off the Handover Function
The Total Time for the Handover Process		
UL User Throughput		
DL User Throughput		

4.1.2 QoE Optimisation

5G native video applications, such as high-resolution videos (e.g. 8K video/VR), need the high transmission bandwidth and are sensitive to the latency. The quality of the user experience (QoE) of the high-resolution video service is more vulnerable to the fluctuations of the wireless transmission, resulting in the video stream jitter and mosaic. Traditional semi-static QoS frameworks cannot efficiently satisfy the QoE requirements of high-resolution video applications; therefore, AI/ML (machine learning) solutions are introduced to optimise the QoE.

4.1.2.1 Definition

The AI use case of the QoE optimisation is to periodically predict the UE uplink radio channel capacity every 100 milliseconds via the RAN (radio access network) intelligent controller (RIC). The prediction will be used to indicate the high-resolution camera's video streaming codec and the gNB (5G NodeB) radio resource scheduler to optimise the user experience of high-resolution videos (to avoid the video stream jitter, mosaic, etc.). Firstly, the RIC will collect data of the base transceiver station (BTS) and the UE (e.g. the cell load), the UE uplink channel measurement results such as the SINR, etc., and perform the uplink channel capacity prediction based on the collected data. The prediction results will be stored and fed back as the input for the next prediction. Secondly, when the RIC predicts the deterioration of the UE uplink capacity, based on the prediction results, it guides the high-resolution cameras to decrease the video streaming codec rate and RAN to reserve proper physical resource blocks (PRB) for the UE to realise the QoE optimisation of high-resolution videos.

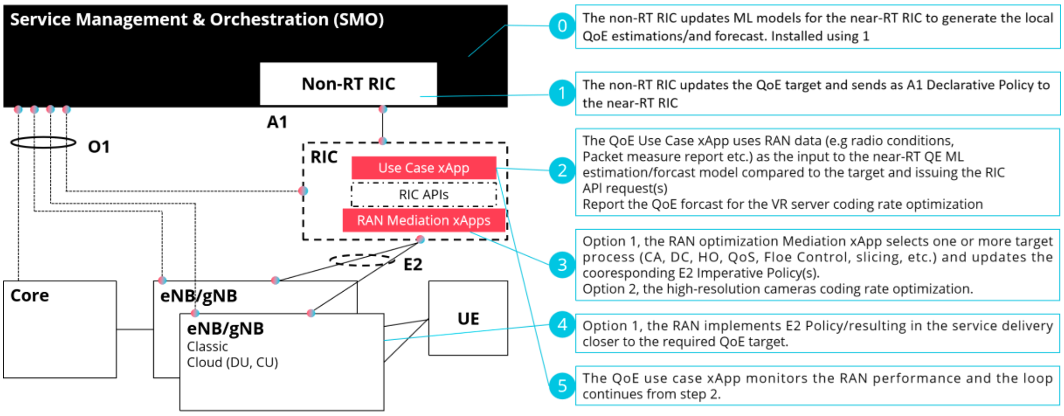


Figure 3: The RIC Architecture

The prediction loop with the feedback can be matched by the LSTM (Long-Short Term Memory) model, the RNN (Recurrent Neural Network) model, the ARMA (Auto Regressive Moving Average) model, etc. Take LSTM as an example. In the LSTM network, the cell state acts as a conveyor transferring the relative "memory" information of the network, and the gates can learn to select the information to "combine" the selected and stored information as the input of the feedback during the training.

4.1.2.2 Testing Environment

4.1.2.2.1 Testing Setup

In this testing case, a 5G UE with high-resolution cameras, a 5G cell under the gNB, the RIC platform, video application servers, and players are needed.

4.1.2.2.2 Testing Configuration

This section focuses on the high user density and the high capacity/throughput in the indoor hot spot scenario. Scenario-specific deployment attributes and expected values are listed in Table 2.

4.1.2.2.3 Testing Procedures

1. Set up the test environment, including the 5G BTS and the RIC, and disable the QoE optimisation service. High-resolution cameras start working.

2. Decrease the camera/UE channel quality, e.g. move the camera to the cell edge. The video stream has the video stream jitter and/or mosaic and the QoE degradation during the test.

3. Enable the QoE optimisation service. The RIC starts the uplink channel capacity prediction.

4. Decrease the camera/UE channel quality, e.g. move the camera to the cell edge. Check whether the video codec automatically adapts to the low resolution (the low resolution could be 2k, depending on the camera) according to the prediction results.

5. Increase the camera/UE channel quality, e.g. move the camera to the cell center. Check whether the video codec automatically adapts to the high resolution (for example, 8k or 4k) according to the prediction results.

4.1.2.2.4 Success Criteria

Disable the QoE optimisation function: the video stream jitter and/or mosaic appear when the channel condition is bad.

Enable the QoE optimisation function: the video codec can automatically adapt to the low/high resolution according to the prediction results when facing the different camera/UE channel qualities. The UE uplink radio channel capacity prediction deviation, calculated by Formula (1), is less than 10%; no video stream jitter or mosaic appears after the video codec adaptation.

$$\text{UE uplink radio channel capacity prediction deviation} = \frac{\text{Abs(Predicted\_Tput} - \text{measured\_Tput)}}{\text{measured\_Tput}} \quad (1)$$

4.1.2.3 Reporting and Analysing Results

Table 8: The Reporting and Analysing Results for the QoE Optimisation

	Disable the Function	Enable the Function
Uplink Capacity Prediction Diviation		
Video Stream Codec		
QoE (Jitter/Mosaic)		

4.1.3 ML-Based AMC

4.1.3.1 Definition

The UL Adaptive Modulation and Coding (AMC) enable both the inner-loop and outer-loop AMC to calculate the PUSCH (physical uplink shared channel) modulation and the coding scheme (MCS) value. However, since the MCS offset calculated by the outer-loop AMC is gradually updated with multiple continuous PUSCH scheduling, the UE with discrete and/or small UL buffer status reports (BSR) cannot obtain a satisfying MCS offset, which will lead to the imperfect UL MCS and result in the low UL SE. To solve this problem, an ML algorithm can be used to infer UL MCS offsets, where the reinforcement learning will be used to maintain a knowledge repository of perfect MCS offsets for the PUSCH scheduling according to different UL channel qualities and the receiving power.

For the DL AMC, in the traditional AMC procedure, for the TDD system, all DL sub-frames share the same DL MCS offsets. However, we may observe the different block error rates (BLER) at different DL sub-frames for different UEs; therefore, the shared MCS offsets will cause the low DL SE. To solve this problem, an ML algorithm can be deployed to learn the best MCS offsets for each DL sub-frame of the UE with the specific channel quality and communication chips. By the clustering algorithm, the grids will be generated, according to the specific channel quality and communication chips, and merged based on a similar BLER. The reinforcement learning will be applied to obtain the MCS offsets for each grid as the knowledge repository. With the ML-based DL AMC, the UE can infer its MCS offset according to the corresponding knowledge repository.

4.1.3.2 Testing Environment

4.1.3.2.1 Testing Setup

This feature is for gNBs.

1. For the Call Quality Test (CQT):
   1) The testing UE should avoid the locations that are too good or too bad. For example, the UL & DL MCS of the testing UE should be in the range of 5~22.
   2) The testing UE application requirements: the testing UE should access the testing cell, run applications with a small BSR for tens of seconds, and then release resources. Then the testing UE should re-access the testing cell and iterate the procedure.

2. For the commercial call test:

The test cell requirement: the UE distribution of the cell should be stable, and the UL&DL load of the cell should be relatively high.

4.1.3.2.2 Testing Configuration

Table 9: The Testing Configuration for the ML-based AMC

Attributes	Expected Values
Carrier Frequency	Sub 6 GHz (For example: 2.6 GHz for CMCC)

4.1.3.2.3 Testing Procedures

1. The CQT：
   - Baseline:
     1) Turn off the feature.
     2) The testing UE starts the application as mentioned in the testing UE application requirements for the CQT in Section 4.1.3.2.1 for one hour.
     3) Record the key KPI counters during Step 2).

   - Proposed feature:
     1) Turn on the feature.
     2) The testing UE starts the same application at the same location as in the baseline for one hour to train the ML model.
     3) The testing UE starts the same application at the same location as in the baseline for one hour.
     4) Record the key KPI counters during Step 3).
     5) Compare the key KPI counters of the baseline and the proposed scheme.

2. The commercial cell test：
   - Baseline:
     1) Turn off the feature.

2) The testing UE starts the application as mentioned in the testing UE application requirements for the CQT in Section 4.1.3.2.1 for one week.
3) Record the key KPI counters during Step 2).

- Proposed feature:
  1) Turn on the feature.
  2) The testing UE starts the same application at the same location as in the baseline for one week to train the ML model.
  3) The testing UE starts the same application at the same location as in the baseline for one week.
  4) Record the key KPI counters during Step 3).
  5) Compare the key KPI counters of the baseline and the proposed scheme.

4.1.3.2.4 Success Criteria

5% + of the average UL SE are improved for all test cells after enabling this feature.

5% + of the average DL SE are improved for all test cells after enabling this feature.

4.1.3.3 Reporting and Analysing Results

Table 10: The Reporting and Analysing Results for the ML-based AMC

	Disable the Feature (baseline)	Enable the Feature (proposed)
Average UL Throughput per PRB (kbps)		
Average DL Throughput per PRB (kbps)		
UL UE Throughput in cells (kbps)		
DL UE Throughput in cells (kbps)		
Initial Success Rate of UL MAC Transmission (%)		
Initial Success Rate of DL MAC Transmission (%)		

4.1.4 Network Orchestration for the Spectrum Sharing

4.1.4.1 Definition

At the early stage of the 5G era, to improve the SE, the spectrum sharing between 4G and 5G is widely deployed. However, with the spectrum sparing, the interference between 4G and 5G is inevitable, and the whole network is not possible to be smoothly transformed to the pure 5G. An AI RAN network orchestration is designed to solve the above-mentioned problems, including the large smart engine (LSE) deployed on the network management for the load prediction model training, the real-time smart engine (RSE) deployed on the network element for the load prediction inference, and the network composer applications, where the clusters of cells will be generated, deployed on the network elements.

For the 4G/5G spectrum sharing, firstly, with the precise prediction of the network load of 4G and 5G cells, we can allocate the whole spectrum to 5G while the 4G load is relatively low with the guarantee of the experience of 4G users (referred to as the pure 5G state), or reallocate proper spectrum resources to 4G users when the load of corresponding 4G cells is relatively high (referred to as the 4G/5G spectrum sharing state), and ensure that the resource allocation strategies change smoothly. Secondly, to alleviate the inter-RAT interference, the cluster-level strategy is used to ensure that the states of cells in the same cluster are unified (either in the pure 5G state or the spectrum sharing state).

4.1.4.2 Testing Environment

4.1.4.2.1 Testing setup

The network orchestration function works based on the FDD Dynamic Spectrum Sharing (DSS), and is supported in the following DSS scenarios:

Scenario 1: The LTE bandwidth is included in the NR bandwidth, which is also called the partial bandwidth DSS scenario. The LTE spectrum is on the low-frequency part of the NR spectrum.

Scenario 2: The LTE bandwidth is completely overlapped with the NR bandwidth. In this situation, the LTE and NR networks share full bandwidth resources, which is also called the full bandwidth sharing DSS.

Testing UEs: At least one 5G-capable UE and one 4G-capable UE should be available.

4.1.4.2.2 Testing Configuration

Table 11: The Testing Configuration for the Network Orchestration for the Spectrum Sharing

Attributes	Expected Values
Carrier Frequency	Sub 6 GHz (For example: 900 MHz for CMCC)
Aggregated System Bandwidth	10 MHz for sub 6 GHz
Sub-Carrier Spacing	15 KHz for sub 6 GHz
Notes	Need LTE cells in other spectrums as the 4G coverage layer

4.1.4.2.3 Testing Procedures

1. Enable the FDD New Radio (FNR) in all of the test cells. Disable the network orchestration feature.

2. The testing UE accesses the SA (Standalone) cell, and starts the driving test (DT) with DL full-buffer applications and UL & DL full-buffer applications, respectively.

3. Record the UE log during Step 2.

4. Enable the network orchestration feature and set the LTE load threshold for switching off DSS LTE to be 20% for all of the testing cells.

5. DSS LTE cells are switched off due to the low LTE load.

6. The testing UE accesses the SA cell, and starts the driving test as the same path as in step 2 with DL full-buffer applications and UL & DL full-buffer applications, respectively.

7. Record the UE log during Step 6.

4.1.4.2.4 Success Criteria

10% of the DT throughput improvement is realised after enabling this feature.

4.1.4.3 Reporting and Analysing Results

Table 12: The Reporting and Analysing Results for the Network Orchestration for the Spectrum Sharing

Indicator	Disable the Function	Enable the Function
The UL UE throughput in cells (kbps)		
The DL UE throughput in cells (kbps)		
The average UL RLC throughput in cells		
The average DL RLC throughput in cells		

4.1.5 Smart Slice Resource Reservation

4.1.5.1 Definition

For services with high availability requirements, we usually reserve the static number of resources via the slicing based on their peak requirements, which always leads to the waste of resources. To ensure the QoS and improve the SE, the ML-based slice resource reservation can be deployed. The ML algorithm is applied to predict the needs of resource blocks (RB) for every slice at different time. Then the prediction results are used to adjust the RB numbers of the static slice resource reservation. With the smart slice resource reservation, we can precisely predict the resource requirements for a specific service quickly and then adjust the number of resources reserved for the service.

4.1.5.2 Testing Environment

4.1.5.2.1 Testing Setup

This feature is for SA gNBs.

4.1.5.2.2 Testing Configuration

Table 13: The Testing Configuration for the Smart Slice Resource Reservation

Attributes	Expected Values
Carrier Frequency	Sub 6 GHz (For example: 2.6 GHz for CMCC)
Aggregated System Bandwidth	100 MHz for sub 6 GHz
Sub-Carrier Spacing	30 kHz for sub 6 GHz
Notes	3 slices with the static resource reservation: 1) Slice 1: 20% RB of the cell will be reserved. 2) Slice 2: 20%. 3) Slice 3: 20%. 4) Default Slice: 0%. The testing UE: 1) 2 UEs, surveillance video, for slice 1. 2) 10 UEs, control signal, for slice 2. 3) 2 UEs, photo uploading, for slice 3. 4) 5 UEs, UL & DL full-buffer, for the default slice.

4.1.5.2.3 Testing Procedures

1. Configure 3 slices as mentioned in 4.1.5.2.2 in the testing cell.

2. The UEs in slice 1 start the surveillance video application for 15 minutes.

3. Record the cell PRB utilization ratio in Step 2. Calculate the value of DeltaPrbUsage1 by Formula (2).

$$\text{DeltaPrbUsageX} = \text{PRB ratio reserved for slice X} - \text{average PRB ratio used by UEs of slice 1 within 15 minutes} \quad (2)$$

4. The UEs in slice 2 start the control signal application for 15 minutes with a period of 10 seconds.

5. Record the cell PRB utilization ratio in Step 4. Calculate the value of DeltaPrbUsage2 by Formula (2).

6. The UEs in slice 3 start the photo uploading application for 15 minutes.

7. Record the cell PRB utilization ratio in Step 6. Calculate the value of DeltaPrbUsage3 by Formula (2).

8. Labeled as the baseline, all UEs in slices 1, 2, 3, and the default slice start their applications by disabling the smart slice resource reservation feature for an hour. Record the key KPI mentioned in 4.1.5.3.

9. Labeled as the proposed feature, all UEs in slices 1, 2, 3, and the default slice start their applications by enabling the smart slice resource reservation feature for an hour. Record the key KPI mentioned in 4.1.5.3.

4.1.5.2.4 Success Criteria

The sum of DeltaPrbUsage1, DeltaPrbUsage2, and DeltaPrbUsage3 is reduced after enabling this feature.

4.1.5.3 Reporting and Analysing Results

Table 14: The Reporting and Analysing Results for the Smart Slice Resource Reservation

	PRB utilization ratio
Disable the feature (baseline)	
Enable the feature (proposed)	

4.1.6 Differentiated Service with the Application Awareness

4.1.6.1 Definition

Different services may have different QoS requirements and correspond to different 5QIs. However, the 5QIs can differentiate services according to QoS characteristics, such as the delay budget, the packet error rate, etc. Nearly the same scheduling strategy is deployed for most services, which may cause a low user experience and/or the low SE. To tackle this problem, the proposed feature can provide different strategies for different services. For example, with the proposed feature, the system is able to identify that the video service comes from YouTube or Hulu, and provide corresponding scheduling strategies.

In the proposed feature, firstly, an ML algorithm in the network system is adopted to precisely identify the type of the service. From the data message of users, the system can obtain the message characteristics, such as the message size, the message period, the service protocols (e.g. HTTP, SMTP), etc., with which the system can match and identify the specific service. Secondly, the network system will implement the appropriate scheduling strategy for the specific service. The whole process is running in a loop, which means the system will keep monitoring/recognizing the user's service and adjusting the corresponding strategy.

4.1.6.2 Testing Environment

4.1.6.2.1 Testing setup

This feature is for SA gNBs.

4.1.6.2.2 Testing Configuration

Table 15: The Testing Configuration for the Differentiated Service with the Application Awareness

Attributes	Expected Values
Carrier Frequency	Sub 6 GHz (For example: 2.6 GHz for CMCC)

4.1.6.2.3 Testing Procedures

1. Disable the feature function.
2. The testing UE runs the web search application for 5 minutes.
3. Record the UE log during Step 2.
4. Enable the feature function.
5. Assign a dedicated Network Slice Selection Assistance Information (NSSAI) for the UE. Enable the uplink pre-scheduling for the UE slice.
6. The UE runs the same application at the same location as in Step 2 for 5 minutes.
7. Record the UE log during Step 6.
8. Compare the key KPI mentioned in 4.1.6.3.

4.1.6.2.4 Success Criteria

20% RTT latency reduction after enabling this feature.

4.1.6.3 Reporting and Analysing Results

Table 16: The Reporting and Analysing results for the Differentiated Service with the Application Awareness

	Disable the Feature	Enable the Feature
The Total Number of TCP Three-Way Handshake SYNACK2ACK		
The Total Number of Downlink TCP Sample Packets in the Cell		
The Total Delay of TCP Core Network RTT (TCP base station sends SYN to the receiver core network SYNACK)		
The Total RTT Delay of the Downlink TCP Sample packets of the Cell		

4.2 Base Station Energy Saving

As the 5G network offers better performance, the power consumption and carbon emissions are substantially increasing. Operators are exploring possible energy-saving technologies to meet performance demands while maintaining the low energy consumption. Therefore, it will be crucial to measure the energy-saving effect and the energy efficiency of the whole network.

4.2.1 Sub-Frame Silence

4.2.1.1 Definition

The basic principle is that when the gNB detects that some downlink symbols are not sending any data, it turns off the RF (radio frequency) hardware, thereby reducing the power consumption of the base station without impacting the user's latency.

4.2.1.2 Testing Environment

4.2.1.2.1 Testing Setup

1. The 5G single-mode base station gNB is configured as the cell with NR 100 MHz bandwidth.

2. The 5G BBU and AAU have been working for at least 30 minutes steadily before the test.

3. The total transmission power of the AAU remains stable during the testing, and the power consumption counter can be used for the power consumption measurement.

4. The UE can access the cell normally.

In this test case, the test will be done at the good, medium, and bad points. Take 2.6 GHz for example. The definition of the good, medium and bad points is:

- Good points: -80 dBm < RSRP.
- Medium points: -100 dBm < RSRP < -80 dBm.
- Bad points (at the cell edge): RSRP < -100 dBm.

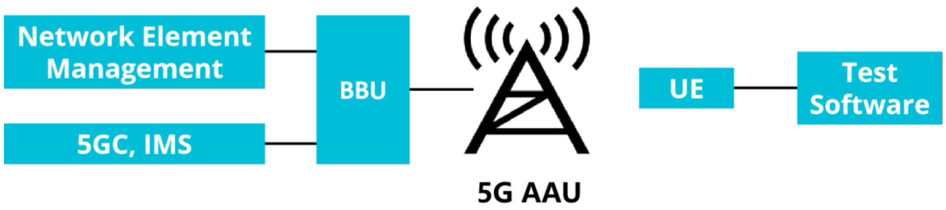


Figure 4: The Testing Environment for the Sub-Frame Silence

4.2.1.2.2 Testing Configuration

Table 17: The Testing Configuration for the Sub-Frame Silence

Attributes	Expected Values
Carrier Frequency	Sub 6 GHz (For example: 2.6 GHz for CMCC)
Aggregated System Bandwidth	100 MHz for sub 6 GHz
Sub-Carrier Spacing	30 kHz for sub 6 GHz
Notes	1) The base station is configured with the maximum transmitting power to meet the enterprise standard requirements. 2) The baseband module and the control module in the 5G BBU are configured according to the S111 configuration. 3) The output power of the AAU is configured as the maximum output power (320 W). 4) The SSB/RMSI (Remaining Minimum System Information) interval is set to 20 milliseconds. 5) The threshold configuration: the actual number of users and the actual RB utilization.

4.2.1.2.3 Testing Procedures

1. All energy-saving functions are turned off. Set the PRB utilization rate of the AAU to 30%.

2. One 5G NR UE initiates the downlink service (UDP service), and the other NR UE initiates the Ping service with a Ping packet of 2000 bytes. Repeat 100 times.

3. Record the data as shown in Section 4.2.1.3.

4. Set the PRB utilization rate of the AAU to 5% and 0, respectively. Repeat steps 2-3.

5. Turn on the sub-frame silence function and turn off the packet accumulation scheduling. Repeat steps 2-4.

6. Turn on the packet accumulation scheduling and set the PRB thresholds for the packet accumulation to 10%, 20%, and 50% respectively.

7. Repeat steps 2-4 at the good, medium, and bad points.

4.2.1.2.4 Success Criteria

After enabling the sub-frame silence, the power consumption of the AAU has been significantly reduced, and the UE data are not much different from those when turning off the sub-frame silence.

For instance, for a 5G single-mode base station with the 64TR AAU and for 2.6 GHz, at 5% PRB utilization, the sub-frame silence can be turned on to obtain at least 20% power saving for the AAU; with 30% PRB utilization, at least 15% power saving effect can be obtained.

4.2.1.3 Reporting and Analysing Results

The following result tables and recorded data can be simplified according to the tests.

1. The AAU & BBU power consumption before and after enabling the sub-frame silence function without the packet accumulation scheduling.

Table 18: The AAU & BBU Power Consumption Without the Packet Accumulation Scheduling

	The PRB Usage = 0		The PRB Usage = 5%		The PRB Usage = 30%	
	Disable the Sub-Frame Silence	Enable the Sub-Frame Silence	Disable the Sub-Frame Silence	Enable the Sub-Frame Silence	Disable the Sub-Frame Silence	Enable the Sub-Frame Silence
AAU Power Consumption (W)						
BBU Power Consumption (W)						

2. The AAU & BBU power consumption before and after enabling the sub-frame silence for the packet accumulation scheduling.

Table 19: The AAU & BBU Power Consumption with the Packet Accumulation Scheduling

Category	Good Point			Medium Point			Bad Point		
	AAU Power Consu-mption (W)	AAU Energy Saving Proporti-on	BBU Power consumpt-ion (W)	AAU Power Consump-tion (W)	AAU Energy Saving Proporti-on	BBU Power Consumpti-on (W)	AAU Power Consump-tion (W)	AAU Energy Saving Proporti-on	BBU Power Consumpt-ion (W)
Disable the Sub-Frame Silence									
Enable the Sub-Frame Silence									
The PRB Threshold for Saving Packets = 10%									
The PRB Threshold for Saving Packets = 20%									
The PRB Threshold for Saving Packets = 50%									

3. The Ping delay and the traffic data of the UE before and after the sub-frame silence function is enabled for the packet accumulation scheduling.

Table 20: The Ping Delay and the Traffic Data of the UE

<table>
<tr><th>Test Position</th><th>Category</th><th>Average Ping Packet delay (ms)</th><th>RSRP</th><th>SINR</th><th>DL RB</th><th>UL RB</th><th>DL GRANT</th><th>UL GRANT</th><th>DL MCS</th><th>UL MCS</th><th>SRS TxPower</th><th>PUSCH TxPower</th><th>DL RANK</th><th>UL RANK</th></tr>
<tr><td rowspan="5">Good Point</td><td>Disable the Sub-Frame Silence</td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td colspan="14">Enable the Sub-Frame Silence</td></tr>
<tr><td>The Packet Saving Threshold = 10%</td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td>The Packet Saving Threshold = 20%</td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td>The Packet Saving Threshold = 50%</td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td rowspan="4">Medium Point</td><td>Disable the Sub-Frame Silence</td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td colspan="14">Enable the Sub-Frame Silence</td></tr>
<tr><td>The Packet Saving Threshold = 10%</td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td>The Packet Saving Threshold = 20%</td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
</table>

	The Packet Saving Threshold = 50%													
Bad Point	Disable the Sub-Frame Silence													
	Enable the Sub-Frame Silence													
	The Packet Saving Threshold = 10%													
	The Packet Saving Threshold = 20%													
	The Packet Saving Threshold = 50%													

4.2.2 Channel Silence

4.2.2.1 Definition

The channel silence refers to the technology of muting some RF channels, with the low traffic, of multi-channel base stations, such as 64/32 channels, thereby reducing the power consumption of the base station.

4.2.2.2 Testing Environment

4.2.2.2.1 Testing Setup

1. Three AAUs are configured as three cells with NR 100 MHz bandwidth. The testing UEs initiate services in each cell so that AAUs can work in the full power state. The cells without UEs are loaded in the BTS simulation mode.

2. Make sure that the 5G BBUs and AAUs have been working stably for more than 30 minutes and have been preheated before the test.

3. The total transmit power of the AAU is stable during the test.

4. The UE can access the cell normally.

5. In this test case, the tests will be done at the good, medium, and bad points. Take 2.6 GHz for example. The definition of the good, medium and bad points is the same as in Section 4.2.1.2.1.

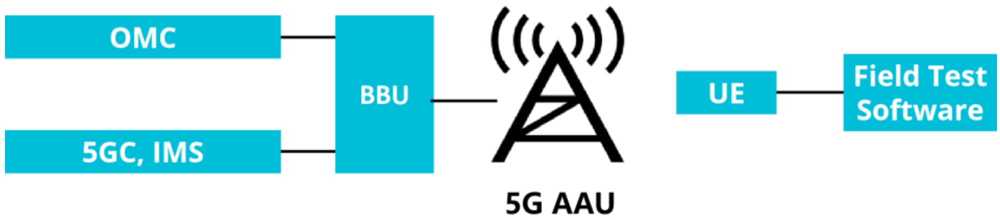


Figure 5: The Testing Environment for Channel Silence

4.2.2.2.2 Testing Configuration

Table 21: The Testing Configuration for the Channel Silence

Attributes	Expected Values
Carrier Frequency	Sub 6 GHz (For example: 2.6 GHz for CMCC)
Aggregated System Bandwidth	100 MHz for sub 6 GHz
Sub-Carrier Spacing	30 kHz for sub 6 GHz
Notes	1) The base station is configured with the maximum transmitting power to meet the enterprise standard requirements.

	2) The 5G BBU is configured with the baseband module and the main control module according to the S111. 3) The output power of the AAU is configured as the maximum output power (320 W). 4) The SSB/RMSI interval is set to 20 milliseconds. 5) Set the energy-saving time, the starting time t1 and the end time t2 of the channel-silence function, and the load threshold.

4.2.2.2.3 Testing Procedures

1. Disable the channel silence function. The testing UE normally initiates the downlink service (UDP service).

2. Use two BBUs when the PRB utilization rate of three AAUs is 30% (since one BBU cannot support three AAUs at the full load simultaneously).

3. The testing UE performs FTP uplink and downlink services in the cell. Perform the tests at the good points, medium points, and bad points, respectively.

4. Record the data as shown in 4.2.2.3.

5. Enable the channel silence function (64T is shut down to 32T) and enable the power compensation. Repeat steps 2-4. Note that the cell SSB coverage performance should be consistent with that before the channel shut down, and the user location remains the same as in Step 3.

4.2.2.2.4 Success Criteria

After the cell channel is silent, the AAU energy consumption is significantly reduced, and the UE data are not much different from those when turning off the function.

For example, for a 5G single-mode base station with the 64TR AAU and for 2.6 GHz, when the PRB utilization rate is 5%, opening the channel silently can obtain at least 20% power saving effect; when the PRB utilization rate is 30%, at least 30% power saving effect can be obtained.

4.2.2.3 Reporting and Analysing Results

The following result tables and recorded data can be simplified according to the tests.

1. The AAU power consumption before and after enabling the channel silence.

Table 22: The AAU Power Consumption

Test Position	Good Point		Medium Point		Bad Point	
Shut Down Mode	Disable the Channel Silence	Enable the Channel Silence	Disable the Channel Silence	Enable the Channel Silence	Disable the Channel Silence	Enable the Channel Silence
AAU Power Consumption						
Energy Saving Ratio of AAU						

2. The BBU power consumption before and after enabling the channel silence.

Table 23: The BBU Power Consumption

Test Position	Good Point		Medium Point		Bad Point	
Shutdown Mode	Disable the Channel Silence	Enable the Channel Silence	Disable the Channel Silence	Enable the Channel Silence	Disable the Channel Silence	Enable the Channel Silence
BBU power Consumption						

3. The UE data before and after enabling the channel silence.

Table 24: The UE Data

Test Position		RSRP	SINR	PDCP Thr. DL	DL RB	DL Grant	DL MCS	SRS TxPower	PUSCH TxPower	DL Rank
Good Point	Disable the Channel Silence									
	Enable the Channel Silence									
Medium Point	Disable the Channel Silence									
	Enable the Channel Silence									
Bad Point	Disable the Channel Silence									
	Enable the Channel Silence									

4.2.3 AAU Shallow Dormancy

4.2.3.1 Definition

The AAU shallow dormancy refers to the technology that the base station turns off analog devices, such as the power amplifier of the 5G AAU, and the AAU enters the shallow dormancy state to reduce the power consumption. Before the AAU enters the shallow-dormant state, online users must be migrated to neighbour AAUs to ensure that services continue.

4.2.3.2 Testing Environment

4.2.3.2.1 Testing Setup

1. The total transmission power of the AAU/RRU remains stable during the test.

2. For the AAU shallow dormancy with the 5G coordination: the 5G base stations gNB1 and gNB2 are respectively connected to two AAUs/RRUs which are configured as CELL1 and CELL2, respectively. CELL1 and CELL2 are configured with 100 MHz and 60 MHz on different frequencies, such as 100 MHz of 2.6 GHz and 2*30 MHz of 700 MHz.

3. For the AAU shallow dormancy with the 4G/5G collaboration: the 4G base station eNB1 and the 5G base station gNB2 are respectively connected to two AAUs/RRUs which are configured as CELL1 and CELL2, respectively.

(a) The 5G Coordination (b) The 4G/5G Collaboration

Figure 6: The Testing Environment for the AAU Shallow Dormancy

4.2.3.2.2 Testing Configuration

Table 25: The Testing Configuration for the AAU Shallow Dormancy

Attributes	Expected Values
Carrier Frequency	Sub 6 GHz(For example: 2.6 GHz for CMCC)
Aggregated System Bandwidth	100 MHz for sub 6 GHz
Sub-Carrier Spacing	30 kHz for sub 6 GHz

Notes	1) The base station is configured with the maximum transmitting power to meet the enterprise standard requirements. 2) 5G BBUs and 4G BBUs are configured with the baseband module and the main control module according to the S111. 3) The output power of the AAU is configured as the maximum output power (320 W). 4) The SSB/RMSI interval is set to 20 milliseconds.

4.2.3.2.3 Testing Procedures

Test whether the cell interacts normally after the energy-saving function is turned on/off, whether the UE is switched smoothly, and whether CELL1 enters/exits the shallow dormancy state normally.

1. The AAU shallow dormancy with the 5G coordination:
    1) Configure the testing environment for the 5G coordination.
    2) Start CELL1 and CELL2.
    3) Configure the load-based shallow dormancy for CELL1, and set the corresponding load threshold of CELL1, such as the PRB utilisation rate, for turning on the shallow dormancy.
    4) Configure CELL2 as the coverage-supplementary cell of CELL1, and set the threshold of CELL2 to start Cell1, such as the PRB utilisation rate.
    5) Two UEs access CELL1 and perform the download service.
    6) Reduce the cell load of CELL1 to reach the threshold for turning on the shallow dormancy.
    7) Check out:
        - whether the AAU of CELL1 enters the shallow dormancy mode;
        - whether CELL1 exchanges the cell load information with CELL2 through the Xn interface, registers the capacity/coverage cell, and deactivates the registration flow;
        - whether two UEs are normally handed over to CELL2.

8) Increase the cell load of CELL2 to reach the CELL1 activation threshold.
9) Check out whether CELL2 exchanges the cell activation signalling via the interface with CELL1.
10) Record the delay from the time when CELL1 receives the cell activation signalling to the time when the cell works normally.

2. The AAU shallow dormancy energy saving through the 4G and 5G collaboration:
    1) Configure the testing system for the 4G/5G collaboration.
    2) Repeat steps 1 2) - 10).

4.2.3.2.4 Success Criteria

The reference power consumption and the activation time are as follows:

The AAU/RRU recovers from the shallow dormancy state to the normal state, which takes less than 30 seconds. After the AAU/RRU enters the shallow dormancy state, the power consumption is reduced to less than 30% of the no-load power consumption.

4.2.3.3 Reporting and Analysing Results

Table 26: The Reporting and Analysing Results for the AAU Shallow Dormancy

State	Power Consumpt-ion Before Enabling the Shallow Dormancy	Power Consumpti-on After Enabling the Shallow Dormancy	Time When the gNB Receives The Command to Enable the Shallow Dormancy (t1)	Time When the gNB Enters the Shallow Dormancy Mode (t2)	t2-t1	Time When the gNB Receives The Command to Disable the Shallow Dormancy (t3)	Time When the gNB Enters the Shallow Dormancy Mode (t4)	t4-t3
Results								

4.2.4 AAU Deep Dormancy

4.2.4.1 Definition

The AAU deep dormancy refers to the technology that the base station turns off the power amplifier, radio frequency, and digital channels of the 5G AAU, and only retains the most basic digital interface circuit work, thereby reducing the power consumption. Before the AAU enters the deep dormant state, online users must be migrated to neighbour AAUs to ensure that services continue.

4.2.4.2 Testing Environment

4.2.4.2.1 Testing Setup

1. The total transmission power of the AAU/RRU remains stable during the test.
2. For the AAU deep dormancy with the 5G coordination: the 5G base stations gNB1 and gNB2 are respectively connected to two AAUs/RRUs which are configured as CELL1 and CELL2, respectively. CELL1 and CELL2 are configured with 100 MHz and 60 MHz on different frequencies, such as 100 MHz of 2.6 GHz and 2*30 MHz of 700 MHz.
3. For the AAU deep dormancy with the 4G/5G collaboration: the 4G base station eNB1 and the 5G base station gNB2 are respectively connected to two AAUs/RRUs which are configured as CELL1 and CELL2, respectively.

(a) The 5G Coordination (b) The 4G/5G Collaboration

Figure 7: The Testing Environment for the AAU Deep Dormancy

4.2.4.2.2 Testing Configuration

Table 27: The Testing Configuration for the AAU Deep Dormancy

Attributes	Expected Values
Carrier Frequency	Sub 6 GHz (For example: 2.6 GHz for CMCC)
Aggregated System Bandwidth	100 MHz for sub 6 GHz
Sub-Carrier Spacing	30 kHz for sub 6 GHz
Notes	1) The base station is configured with the maximum transmitting power to meet the enterprise standard requirements. 2) 5G BBUs and 4G BBUs are configured with the baseband module and the main control module according to the S111. 3) The output power of the AAU is configured as the maximum output power (320 W). 4) The SSB/RMSI interval is set to 20 milliseconds.

4.2.4.2.3 Testing Procedures

Test whether the cell interacts normally after the energy-saving function is turned on/off, whether the UE is switched smoothly, and whether CELL1 enters/exits the deep dormancy state normally.

1. The AAU deep dormancy with the 5G Coordination:
    1) Configure the testing environment for the 5G coordination.
    2) Start CELL1 and CELL2.
    3) Configure the load-based deep dormancy for CELL1, and set the corresponding load threshold of CELL1, such as the PRB utilisation rate, for turning on the deep dormancy.
    4) Configure CELL2 as the coverage-supplementary cell of CELL1, and set the threshold of CELL2 to start Cell1, such as the PRB utilisation rate.
    5) Two UEs access CELL1 and perform the download service.
    6) Reduce the cell load of CELL1 to reach the threshold for turning on the deep dormancy.

7) Check out:
    - whether the AAU of CELL1 enters the deep dormancy mode;
    - whether CELL1 exchanges the cell load information with CELL2 through the Xn interface, registers the capacity/coverage cell, and deactivates the registration flow;
    - whether two UEs are normally handed over to CELL2.
8) Increase the cell load of CELL2 to reach the CELL1 activation threshold.
9) Check out whether CELL2 exchanges the cell activation signalling via the interface with CELL1.
10) Record the delay from the time when CELL1 receives the cell activation signalling to the time when the cell works normally.

2. The AAU deep dormancy energy with the 4G and 5G collaboration:
    1) Configure the testing system for the 4G/5G collaboration.
    2) Repeat steps 1 2) - 10).

4.2.4.2.4 Success Criteria

The reference power consumption and activation time are as follows:

It takes less than 5 minutes for the AAU/RRU to recover from the deep dormancy state to the normal state; after the AAU/RRU enters the deep dormancy, the power consumption is reduced to less than 70% of the no-load power consumption.

4.2.4.2.5 Reporting and Analysing Results

Table 28: The Reporting and Analysing Results for the AAU Deep Dormancy

State	Power Consumpt-ion Before Enabling	Power Consumpti-on After	Time When the gNB Receives the Command to Enable the	Time When the gNB Enters the Deep	t2-t1	Time When the gNB Receives the Command to Disable the	Time When the gNB Receives the Command to Enable the	t4-t3

	the Deep Dormancy	Enabling the Deep Dormancy	Deep Dormancy (t1)	Dormancy Mode (t2)		Deep Dormancy (t3)	Deep Dormancy (t4)	
Results								

4.2.5 Energy Efficiency

4.2.5.1 Definition

The energy efficiency (EE) can be defined as the ratio of the data transfer rate to the total power consumption and is considered as an important design indicator for 5G networks. Many factors, such as antenna counts, bandwidth, and base station density, need to be considered to measure the overall power consumption of 5G networks.

4.2.5.2 Testing Environment

4.2.5.2.1 Testing Setup

1. The test environment includes more than 5 NR base stations and 5 LTE base stations.

2. 4G LTE cells and 5G NR cells are configured in the base stations, such as 4G 3*20 MHz inter-frequencies and 2.6 GHz 100 MHz. The corresponding core network and other equipment are connected normally.

4.2.5.2.2 Testing Configuration

The base station is configured with several of energy-saving functions mentioned above, including the sub-frame silence, the channel silence, and the deep dormancy.

Table 29: The Testing Configuration for the Energy Efficiency

Attributes	Expected Values
Carrier Frequency	Sub 6 GHz (For example: 2.6 GHz for CMCC)
Aggregated System Bandwidth	100 MHz for sub 6 GHz

Sub-Carrier Spacing	30 kHz for sub 6 GHz
Notes	1) The transmission power and control mechanism of the common channel, the control channel, and the service channel meet the requirements of the enterprise standard. 2) The output power of AAU is configured as the maximum output power (320 W). 3) The SSB/RMSI interval is set to 20 milliseconds.

4.2.5.2.3 Testing Procedures

The test verifies the overall EE change before and after the energy-saving functions mentioned in 4.2.5.2.2 work. The ratio (b/J) of traffic transferred to the total power consumption during the test interval is measured.

1. Close energy-saving functions, get the traffic data in the network and the power consumption of all the base stations, and measure the EE.

2. Open energy-saving functions, get the traffic data in the network and the power consumption of all the base stations, and measure the EE.

4.2.5.2.4 Success Criteria

The overall EE can increase at least 20% after energy-saving functions works in the same scenario.

4.2.5.3 Reporting and Analysing Results

Table 30: The Reporting and Analysing Results for the Energy Efficiency

	Closing the energy-saving functions	Opening the energy-saving functions
The energy efficiency		

5 ENHANCEMENT OF EXISTING CAPABILITIES

This section includes testing requirements specific to certain services and applications.

5.1 Uplink Centric Evolution

For a long time, mobile communication technologies have mainly focused on satisfying consumers' downlink experience and allocating downlink resources far more than uplink resources. However, with the development of various interactive businesses such as live streaming and cloud gaming, the impact of the uplink on business experience is increasing rapidly.

5.1.1 DFT-s-OFDM Waveform Test

5.1.1.1 Definition

In 3GPP, DFT-s-OFDM is defined as another uplink transmission waveform, besides CP-OFDM. DFT-s-OFDM, with the lower PAPR, leads to the lower MPR and it could increase the uplink output power which benefits the uplink coverage of bad points. Details are described in Section 6.2.2 of [2].

5.1.1.2 Testing Environment

5.1.1.2.1 Testing Setup

This test is for NR TDD/FDD cells.

For the single-user (SU) static test, choose bad points/indoor points with the weak coverage (with uplink rank1).

For the SU driving test, the driving speed should be under 30 km/h.

5.1.1.2.2 Testing Configuration

CP-OFDM configuration: DMRS-UplinkConfig::transformPrecodingDisabled

DFT-s-OFDM configuration: DMRS-UplinkConfig::transformPrecodingEnabled

5.1.1.2.3 Testing Procedures

1. The SU static test:
    1) Identify a location(s) which is/are the bad point(s) (SSB RSRP < 105 dBm).
    2) Connect one UE to the sector and ensure there is only this UE connected to the sector.
    3) Configure CP-OFDM.
    4) Measure the L1 and the PDCP layer throughput with the uplink UDP full buffer service. Measure the PUSCH output power.
    5) Configure DFT-s-OFDM and repeat 4).
    6) The test duration should be at least 3 minutes and the maximum/minimum/average values should be reported.

Note: ensure that the UE can only use rank1 with CP-OFDM and the maximum uplink power in the test point.

2. The SU driving test:
    1) Identify the driving route including the good point (SSB RSRP ≤ 80 dBm), the medium point (105 dBm ≤ SSB RSRP < 80 dBm) and the bad point (SSB RSRP < 105 dBm).
    2) Repeat steps 1 2) to 5).
    3) Throughput values should be reported compared with the distance between the gNB and the device.

5.1.1.2.4 Success Criteria

In the static test, the UE can transmit with higher output power with DFT-s-OFDM than with CP-OFDM. The uplink throughput with DFT-s-OFDM should be higher than that with CP-OFDM in these test points.

In the driving test, when the UE is in the area of bad points, the PUSCH output power with DFT-s-OFDM should be higher than that with CP-OFDM and it also brings higher uplink throughput.

5.1.1.3 Reporting and Analysing Results

For the static test, the performance could be showed as table below:

Table 31: The Reporting and Analysing Results for the DFT-s-OFDM Waveform Test

	SSB RSRP (dBm)	SSB SINR (dB)	PUSCH output power (dBm)	UL Rank	UL MCS	UL Mac throughput (Mbps)
CP-OFDM						
DFT-s-OFDM						

For the driving/coverage test, the performance could be showed as the trendline below (throughput vs distance, MCS vs distance, etc.):

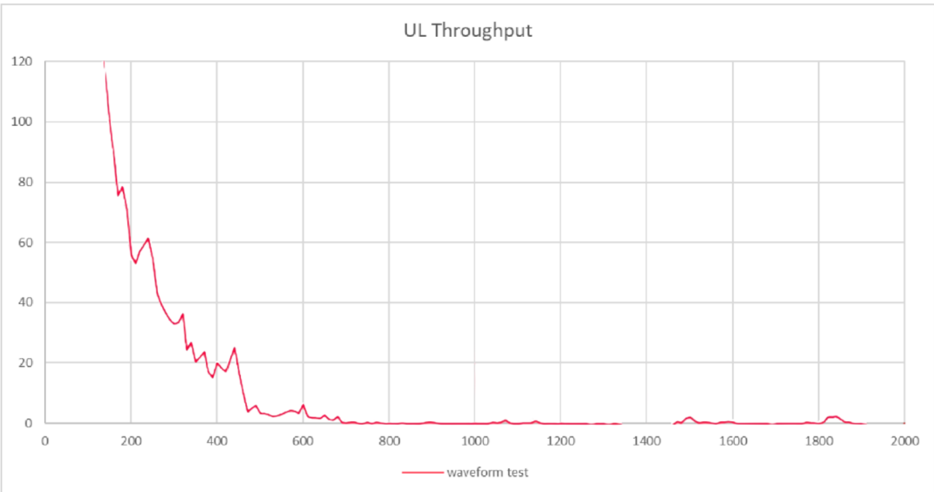


Figure 8: The Performance of the Driving/Coverage Test

5.2 Massive MIMO Evolution

5.2.1 Codebook Type 2 for MU-MIMO, DL Capacity Increase

5.2.1.1 Definition

In the 3GPP R16 vision, codebook type2 is used to increase the accuracy of the downlink PMI weight. Details are described in Section 5.2.2.2.5 in [3].

5.2.1.2 Testing Environment

5.2.1.2.1 Testing Setup

This test is for NR TDD/FDD cells with the downlink PMI weight.

For the SU static test, choose the good/medium/bad points.

For the SU driving test, the driving speed should be under 30 km/h.

For the multi-user (MU) static test:

1) Devices distribute in the sector uniformly.
2) Devices distribute in a small area in the sector.

5.2.1.2.2 Testing Configuration

CodebookConfig-r16:

numberOfPMI-SubbandsPerCQI-Subband-r16{1,2}

paramCombination-r16{1,2,3,4,5,6}

typeII-RI-Restriction-r16 (bit string size 4)

The configuration depends on the gNB implement and the device capability. A more accurate configuration provides better performance and costs more reporting resources (PUSCH).

5.2.1.2.3 Testing Procedures

1. The SU static test:
   1) Identify a location(s) including the good point (SSB RSRP ≤ 80 dBm), the medium point (105 dBm ≤ SSB RSRP < 80 dBm), and the bad point (SSB RSRP < 105 dBm).
   2) Connect one UE to the sector and ensure that there is only this UE connected to the sector.
   3) Configure CodebookConfig as Type1.
   4) Measure the L1 and the PDCP layer throughput with the downlink TCP/UDP full buffer service.
   5) Configure CodebookConfig-r16 as Type2 and repeat 4).
   6) The test duration should be at least 3 minutes and the maximum/minimum/average values should be reported.

2. The SU driving test:
   1) Identify the driving route including the good point (SSB RSRP ≤ 80 dBm), the medium point (105 dBm ≤ SSB RSRP < 80 dBm), and the bad point (SSB RSRP < 105 dBm).
   2) Repeat steps 1 2) to 5).
   3) Throughput values should be reported compared with the distance between the gNB and the device.

3. MU static test:
   1) Identify locations distributing uniformly in the sector.
   2) Connect 2 (or more, depending on the product capability) UEs to the sector and ensure that there is no more UE connected to the sector.
   3) Configure CodebookConfig as Type1.

4) Measure the L1 and the PDCP layer throughput with the downlink TCP/UDP full buffer service.
5) Configure CodebookConfig-r16 as Type2 and repeat 4).
6) The test duration should be at least 3 minutes and maximum/minimum/average values should be reported for total throughput and each of the devices.

5.2.1.2.4 Success Criteria

The downlink throughput with type2 codebook in all tests is better than that with type1 codebook.

5.2.1.3 Reporting and Analysing Results

The reporting and analysing results are listed in Table 32.

Table 32: The Reporting and Analysing Results for the Codebook Type 2 for MU-MIMO, DL Capacity Increase

	SSB RSRP (dBm)	SSB SINR (dB)	DL Rank (SU)/Layer (MU)	DL MCS	DL Mac throughput (Mbps)
SU Codebook Type I					
SU Codebook Type II					
MU Codebook Type I					
MU Codebook Type II					

For the driving/coverage test, the performance could be showed as the trendline below (throughput vs distance, MCS vs distance, etc.):

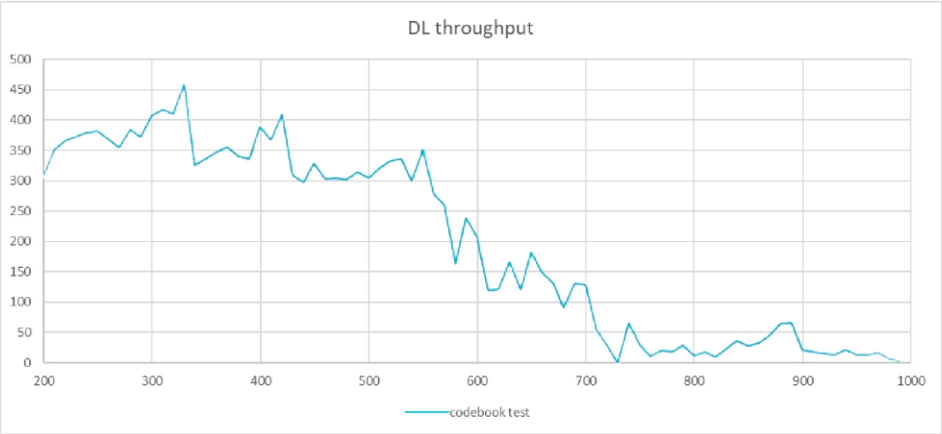


Figure 9: The Performance of the Driving/Coverage Test

5.3 URLLC Enhancement

5.3.1 Uplink Pre-Allocation for Delay Sensitive Services

5.3.1.1 Definition

The cloud-based Entertainment (AR/VR), online gaming, intelligent transportation, and industrial automation are some examples of Ultra-Reliable Low-Latency Communications (URLLC). For services demanding the low latency, 3GPP introduced some features like the large sub-carrier spacing, the shortened HARQ, etc. As a complement, the uplink pre-allocation feature helps to improve the latency performance one step further for delay-sensitive services.

During the uplink pre-allocation, the UEs with delay-sensitive services are assigned with a specific 5QI and the gNB proactively sends uplink scheduling indications to the UE. With the uplink pre-allocation, UEs do not need to send the SR (Scheduling Request) to the gNB, therefore the latency performance is improved. With this feature, specific UEs are allocated with PUSCH RB resources for a pre-determined period and size.

5.3.1.2 Testing Environment

5.3.1.2.1 Testing Setup

The UE under the test is located under the coverage of the 5G SA gNB.

The UE is assigned with some specific delay-sensitive services.

To observe the latency improvement in radio, the test can be performed in two different methods:

- The UE under the test is assigned with a specific 5QI (e.g. Extended 5QI) via PCF and the gNB is configured to pre-allocate uplink resources for the related 5QI.
- Without PCF, the uplink pre-allocation is done for all UEs, only to observe the radio performance (the test should be performed during non-busy hours).

5.3.1.2.2 Testing Configuration

1. For the first method:
    1) PCF is configured such that the UE is assigned with a specific 5QI (e.g. Extended 5QI - 140).
    2) The gNB is configured such that the uplink pre-allocation is assigned for specific 5QIs. For this purpose, the uplink pre-allocation duration, e.g. 200 milliseconds, and the uplink pre-allocation packet size, e.g. 100 Bytes, are configured.

2. For the second method:
   The gNB is configured such that the uplink pre-allocation is assigned for all types of traffic (cell-based). For this purpose, the uplink pre-allocation duration, e.g. 200 milliseconds, and the uplink pre-allocation packet size, e.g. 500 Bytes, are configured.

5.3.1.2.3 Testing Procedures

1. Deactivate the uplink pre-allocation feature in the gNB.

2. The UE is located under the testing gNB and registered to 5GC.

3. Start the Ping test from the UE to the server (set the Ping interval less than the uplink pre-allocation duration, e.g. 100 milliseconds, and the Ping size less than the uplink pre-allocation packet size, e.g. 32 Bytes).

4. Observe the average end-to-end (e2e) Ping delay for some amount (e.g. 20 pings).

5. Measure the Core Network (CN) delay (upper side of the gNB) in Figure 10 (the interval between T2 and T1).

Figure 10: Overview of the Test Measurement Configuration

6. Calculate the radio latency by subtracting the CN delay from the e2e delay as a baseline when the feature is not activated.

7. Activate the uplink pre-allocation feature in the gNB:
   1) For the first method, activate the feature based on a specific 5QI.
   2) For the second method, activate the feature for all the traffic (cell-based).

8. De-register and register the test UE to 5GC.

9. For the first method, observe that the PDU Session Setup Request with the specific 5QI (e.g. 5QI-140) is assigned with the help of PCF.

For the second method, observe that the normal 5QI is assigned.

10. Repeat steps 3 and 4.

11. Repeat Step 6 to calculate the radio latency. Use the CN delay measured in Step 5.

5.3.1.2.4 Success Criteria

1. In Step 6, note that the calculated radio latency when the feature is not activated.

2. In Step 11, note that the calculated radio latency when the feature is activated (in any of the methods).
3. Compare both results and observe that the uplink pre-allocation for delay-sensitive services feature brings the significant latency improvement (especially because of skipping the SR procedure).

5.3.2 DS Frame Structure

5.3.2.1 Definition

In the traditional TDD frame structure, the number of U sub-frames and the number of D sub-frames in a radio frame are unbalanced, which increases the final service delay. For example, in a 5-millisecond single-period frame structure, the uplink data arrival time is different, and the uplink latency can fluctuate greatly.

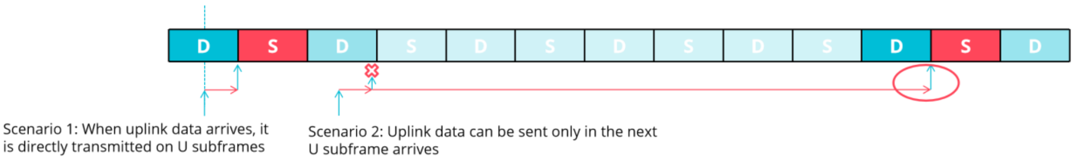


Figure 11: The Traditional TDD Frame Structure

To avoid the latency increase caused by the imbalance between the number of D sub-frames and the number of U sub-frames in TDD, the DS frame structure can be used. [4] The sub-frame ratio of the DS frame structure is as follows, including S sub-frame details: the uplink/downlink conversion gap (2 symbols) and U (12 symbols):

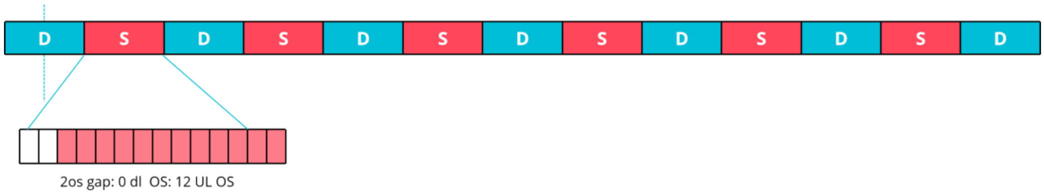


Figure 12: The Sub-Frame Ratio of the DS Frame Structure

Compared with the traditional frame structure, the numbers of U and D sub-frames in the DS frame structure are more balanced, and the latency of sub-frames is more constant.

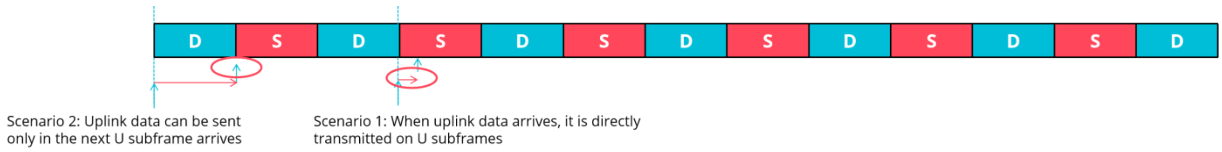


Figure 13: The DS Frame Structure

5.3.2.2 Testing Environment

5.3.2.2.1 Testing Setup

The DS frame structure is one of the key technologies for URLLC. Therefore, locating the test UE under the coverage of the SA gNB can take advantage of the DS frame structure better.

5.3.2.2.2 Testing Configuration

Table 33: The Testing Configuration for the DS Frame Structure

Attributes	Expected Values
Carrier Frequency	Sub 6 GHz (For example: 4.9 GHz for CMCC)
Aggregated System Bandwidth	100 MHz for sub 6 GHz
Sub-Carrier Spacing	30 kHz for sub 6 GHz
Slot Length	0.5 ms (14 symbol)
Special Time Slot	0:2:12 (DL: Gap: UL)
Frame Structure	1 millisecond (D/S)

5.3.2.2.3 Testing Procedures

1. The cell works properly, and the frame structure configuration period is 1 millisecond.
2. Connect the testing UE to the cell of the gNB.
3. The UE originates Ping packets to the server at excellent (SSB RSRP = -65 dBm), good (SSB RSRP = -75 dBm), medium (SSB RSRP = -85 dBm), and bad (SSB RSRP = -96 dBm) points. The Ping packets are 80 Bytes in size, and the interval between Ping packets is 11 millisecond, ping 100 consecutive times.
4. Count the latency of Ping packets.
5. Change the frame structure configuration to 2.5-millisecond dual-period 5D3U2S or 1D3U1S (2.5 milliseconds), and repeat Step 3.

5.3.2.2.4 Success Criteria

Compared with other frame structures, the DS frame structure reduces the maximum transmission latency of uplink and downlink services and improves the average delay.

5.3.2.3 Reporting and Analysing Results

Table 34: The Reporting and Analysing Results for the DS Frame Structure

	The Average Latency	The Maximum Latency	The Minimum Latency
DS frame structure			
5D3U2S or 1D3U1S			

6 MAXIMISE SPECTRUM VALUE

6.1 Duplex Evolution

With the rapid development of 5G, the 5G network requires to flexibly meet differentiated services demands of the uplink and the downlink performance. The flexible duplex is an important solution to provide different uplink and downlink performances. However, the cross-link interference severely limits the performance of the flexible duplex, and the interference coexistence evaluation system and interference optimisation solution are required to be further studied and tested by the field trial.

6.1.1 Cross-Link Interference

6.1.1.1 Definition

1. Slot AMC: The gNB can distinguish the different cross-link interference levels in each slot to adaptively adjust the modulation and coding based on the channel quality, respectively.

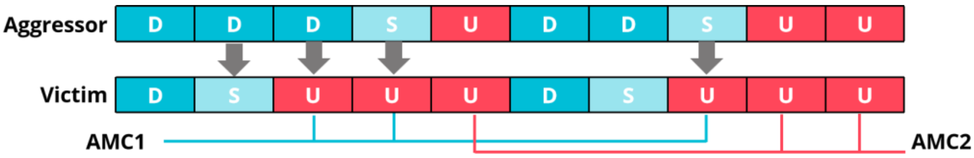


Figure 14: Slot AMC

2. Sounding reference signal (SRS) configuration optimisation: the SRS can be configured in the slot where there is no suffering from cross-link interference.

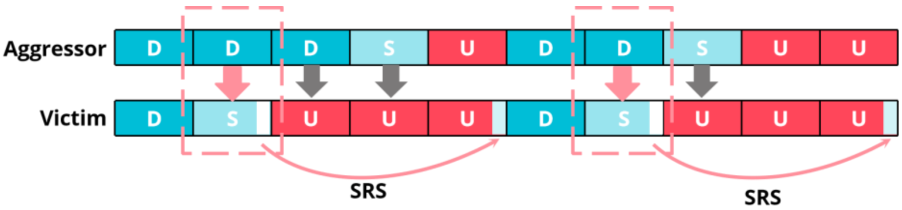


Figure 15: SRS Configuration Optimisation

3. Interference identification: a reference signal can be designed for the victim gNB to identify which gNBs generate the strong cross ink interference. Some solutions between the victim gNB and the aggressor gNB for mitigating remote interference can be used according to the interference identification. The RIM-RS (remote interference management - reference signal) can be reused in this case to identify the aggressor gNB.

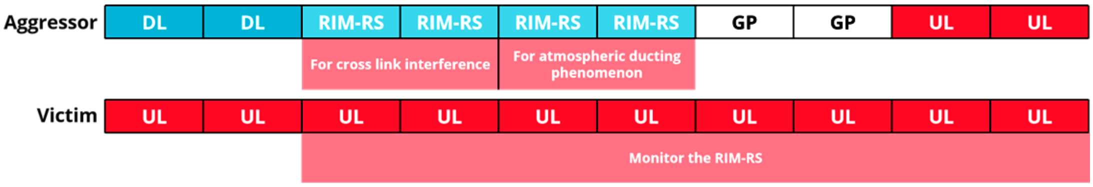


Figure 16: Interference Identification

4. Interference cancellation: a method of the interference cancellation is proposed to reduce the cross-link interference. For the PDCCH (physical downlink control channel) interference of the aggressor gNB, some PRBs are designed to be muted at the first PDCCH symbol of the victim gNB, and the channel estimation of the interference signal can be measured at the muted PRB. For the PDSCH (physical downlink shared channel) interference of the aggressor gNB, the channel estimation of interference can be measured by the pilot or the reference signal. According to the channel estimation of interference, the interference can be reduced by the equalization demodulation.

6.1.1.2 Testing Environment

6.1.1.2.1 Testing Setup

A 5G system in a SA architecture is available (Option2).

At least two UEs with two PCs equipped with the KPI collector software and GPS are needed, which can obtain the key indicators such as SSB RSRP, SSB SINR, PDCP throughput, MCS, PRB, Noise Floor, location, etc.

Deployment scenarios: suitable for the dense urban or indoor hot spot.

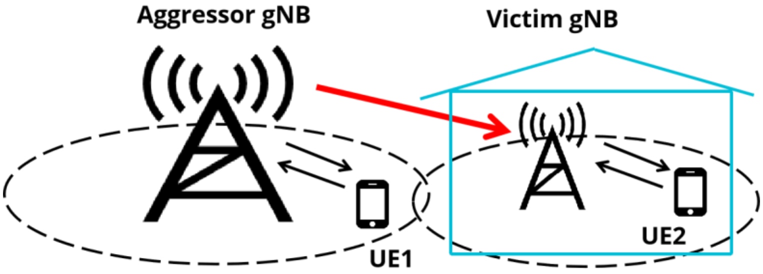


Figure 17: The Deployment Scenario

6.1.1.2.2 Testing Configuration

Table 35: The Testing Configuration for the Cross Link Interference

Attributes	Expected Values
Carrier Frequency	Sub 6 GHz
Sub-Carrier Spacing	30 kHz
NR Architecture	SA
Aggregated System Bandwidth	100 MHz
NR Transmit Power	Not less than 200 W
BS Antenna Elements	64T64R
UE Antenna Elements	2T4R
Frame Structure	Aggressor gNB: DDDSUDDSUU Victim gNB: DSUUUDSUUU
PRACH Format	Format0/Format B4/Format C2
PRACH Period	10 milliseconds
PUCCH Format	Format0/Format1/Format2/Format3
…	…

6.1.1.2.3 Testing Procedures

6.1.1.2.3.1 Slot AMC and SRS Configuration Optimisation

1. The testing UE1 locked on the aggressor gNB is placed in the direction towards the victim gNB (as shown in Figure 17) and starts the downlink full-butter TCP service. The downlink full-buffer TCP service lasts at least 30 minutes.

2. During Step 1, the testing UE2 locked on the victim gNB is placed indoors and starts the uplink full-buffer TCP service with the Slot AMC and SRS configuration optimisation turned on.

3. The UE2 slowly moves around in the testing area for at least 15 minutes.

Note: If the victim gNB is the pico or micro BS deployed indoors, the UE2 is tested only indoors; if the victim gNB is the macro BS deployed outdoor, it's better to be tested outdoor.

4. Get the key indicators as described in Section 6.1.1.2.1 through the KPI collector software and GPS.

5. Turn off the Slot AMC and SRS configuration optimisation. Repeat steps 2 and 3.

6.1.1.2.3.2 **Interference Identification**

1. The testing UE1 locked on the aggressor gNB is placed in the direction towards the victim gNB and starts the downlink full-butter TCP service. The downlink full-buffer TCP service lasts at least 30 minutes.

2. The victim gNB and the aggressor gNB turn on the function of the interference identification.

3. During Step 1, the testing UE2 locked on the victim gNB is placed indoors and starts the uplink full-buffer TCP service.

4. The testing UE2 slowly moves around in the testing area for at least 15 minutes.

5. Get the key indicators as described in Section 6.1.1.2.1 through the KPI collector software and GPS.

6.1.1.2.3.3 **Interference Cancellation**

1. The testing UE1 locked on the aggressor gNB is placed in the direction towards the victim gNB (as shown in Figure 17) and starts the downlink full-butter TCP service. The downlink full-buffer TCP service lasts at least 30 minutes.

2. During Step 1, the testing UE2 locked on the victim gNB is placed indoors and starts the uplink full-buffer TCP service with the PDCCH interference cancellation turned on.

3. The UE2 slowly moves around in the test area for at least 15 minutes.

Note: If the victim gNB is the pico or micro BS deployed indoors, the UE2 is tested only indoors; if the victim gNB is the macro BS deployed outdoor, it's better to be tested outdoor.

4. Get the key indicators as described in Section 6.1.1.2.1, through the KPI collector software and GPS.

5. Turn off the PDCCH interference cancellation and turn on the PDSCH interference cancellation. Repeat steps 2 and 3.

6.1.1.2.4 Success Criteria

1. The slot AMC and SRS configuration optimisation: It can be measured that the uplink throughput of UE2 locked in the victim cell is improved by at least 30%.

2. The interference identification: it can be verified that if the power of the cross-link interference is higher than the interference identification threshold, the victim gNB can obtain the gNB-ID of the aggressor gNB by the reference signal.

3. The interference cancellation: It can be measured that the power of the interference calculated by the victim gNB noise floor is reduced at least 10-30 dB for the PDCCH interference cancellation and 20-40 dB for the PDSCH interference cancellation.

6.1.1.3 Reporting and Analysing Results

Table 36: The Reporting and Analysing Results for the Cross Link Interference

	Victim gNB Noise Floor (dBm/MHz)	SSB RSRP (dBm)	SSB SINR	MCS	PDCP Throughput (Mbps)
The Slot AMC					
The SRS Configuration Optimisation					
The Interference Identification					
The PDCCH Interference Cancellation					
The PDSCH Interference Cancellation					

6.1.2 Sub-Band Non-Overlapping Full Duplex

6.1.2.1 Definition

The sub-band non-overlapping full duplex is at the gNB side only, while the half-duplex operation is assumed at the UE side. On the gNB side, the simultaneous existence of the downlink and uplink within a conventional TDD band is allowed, while the frequency sub-band for the uplink and downlink is non-overlapping.

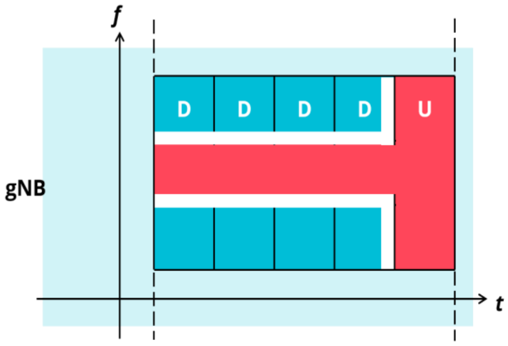
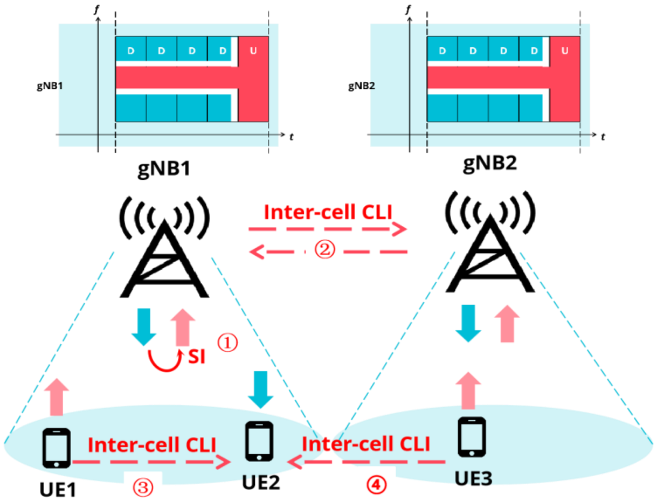
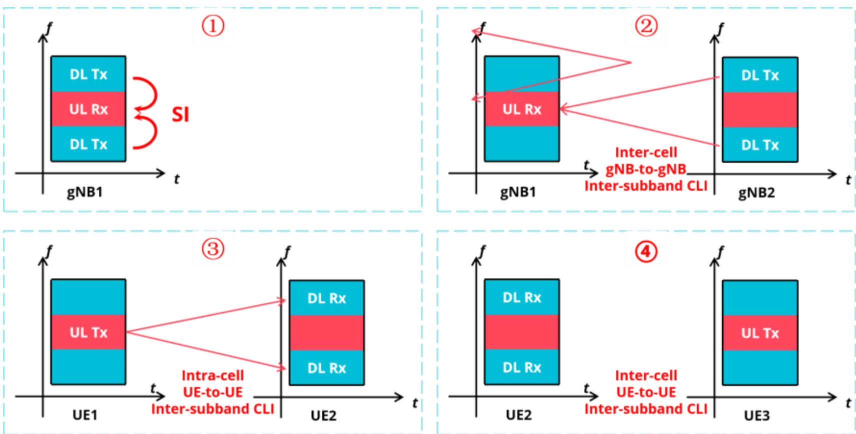


Figure 18: Demonstration for the Sub-Band Non-overlapping Full Duplex

A demonstration of the UL/DL time-frequency resource partitioning manner for the sub-band non-overlapping full-duplex is shown in Figure 19.



(a)



(b)

Figure 19: The Interference Characterization in the Sub-Band Non-overlapping Full Duplex Network

As shown in Figure 19, in a multi-cellular network, the same UL/DL time-frequency resource partitioning manner may be used among neighbour cells. It will introduce more complex interference types, including:

- The Self-interference (SI) at the gNB side. In this case, the DL transmission may cause the non-negligible self-interference to the UL reception at the gNB side.

- The inter-cell gNB-to-gNB inter-sub-band cross-link interference (CLI). In this case, the DL transmission from neighbour cells (e.g. gNB2) may cause the non-negligible inter-sub-band cross-link interference to the UL reception at the local cell (e.g. gNB1).
- The intra-cell UE-to-UE inter-sub-band CLI. In this case, the UL transmission from other UEs in the same cell may cause the non-negligible inter-sub-band cross-link interference to the DL reception at the local UE.
- The inter-cell UE-to-UE inter-sub-band CLI. In this case, the UL transmission from other UEs in neighbour cells may cause the non-negligible inter-sub-band cross-link interference to the DL reception at the local UE.

In a commercial network, the sub-band analog filter is not supported in the TDD transceiver at both the gNB side and the UE side. Nevertheless, for the sub-band non-overlapping duplex operation, the legacy TDD transceiver at the gNB side will receive all the signal power in one frequency band, which may cause the analog-to-digital converter (ADC) saturation and receive blocking. Therefore, the enhancement of the transceiver architectures at the gNB side to involve the sub-band analog filter can be considered to mitigate self-interference and/or the inter-cell gNB-to-gNB inter-sub-band CLI at the gNB side.

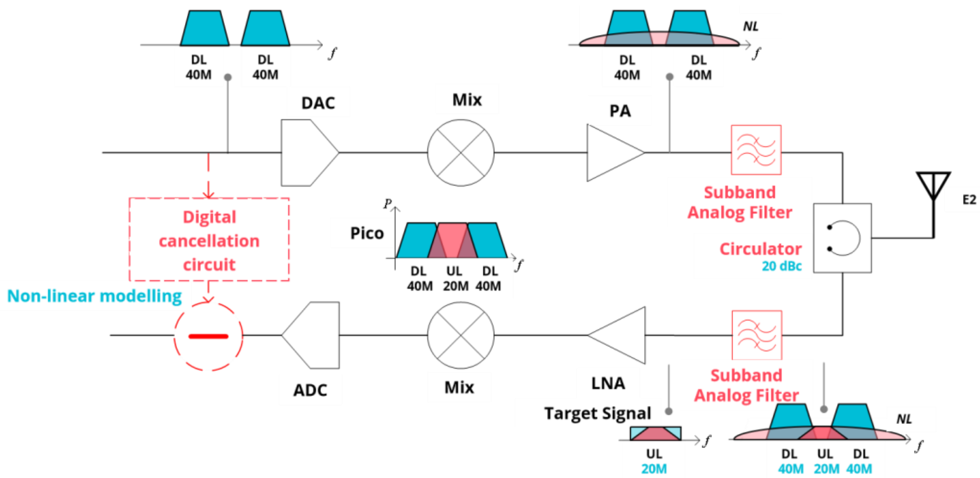


Figure 20: Demonstration of the Enhanced Transceiver Architectures at the gNB Side

A demonstration of the enhanced transceiver architecture for the sub-band non-overlapping duplex operation at the gNB side is shown in Figure 20. In this case, frequency-fixed or frequency-tunable sub-band analog filters are added between LNA and PA to avoid blocking issues, and an additional digital cancellation circuit may be involved to mitigate the residual self-interference.

The minimum RF impact is expected on the UE side. The intra-cell and /or inter-cell UE-to-UE inter-sub-band CLI may be handled by the gNB scheduling, which is up to the networking implementation.

6.1.2.2 Testing Environment

6.1.2.2.1 Testing Setup

The following three deployment scenarios and test tasks can be considered to verify the performance gains of sub-band non-overlapping duplex operation.

1. Scenario 1: Factories
    - Task 1: The cell capacity
        1) The cell configuration: all RRUs connect to the same BBU.
        2) The traffic type: the burst traffic.
        3) The metrics: the downlink average spectral efficiency, the uplink average spectral efficiency, the downlink 5th percentile user spectral efficiency, the uplink 5th percentile user spectral efficiency, the latency, RSRP, SINR, the interference over thermal (IoT).
    - Task 2: Support the delay-sensitive traffic
        1) The cell configuration: all RRUs connect to the same BBU.
        2) The traffic type: the delay-sensitive traffic.
        3) The metrics: the UE capacity, i.e. the number of UEs wherein X% UEs with PER ≤ 1% and within certain PDB (packet delay budget) requirements.

Note: The exact amount of X needs to be determined based on feedback from the industry, which means it depends on the industry capacity.

2. Scenario 2: Macro scenarios
   - Task 3: UL coverage
     1) The cell configuration: the signal cell.
     2) The traffic type: the full buffer.
     3) The metrics: the UL coverage.

6.1.2.2.2 Testing Configuration

1. The UL/DL time-frequency resource partitioning manner: See Figure 18. In the DL dominate slot, there are 20 MHz UL in the middle.

2. For Task 1, the resource utilization (RU) ratio sets as [30%], [50%], [80%], etc.

3. The BS antenna configurations (including the antenna element number and the TRXU number) for both scenarios are up to the industry capacity.

4. For Scenario 1 (factories), other scenario-specific deployment attributes and expected values are listed in Table 2 for the indoor hot spot scenario, only applying the parameters for sub 6 GHz.

5. For Scenario 2 (macro scenarios), other scenario-specific deployment attributes and expected values are listed in Table 5 for the rural scenario, only applying the parameters for sub 6 GHz.

6.1.2.2.3 Testing Procedures

6.1.2.2.3.1 Cell Capacity

The test is under Task 1.

Baseline: TDD configurations with the DDDSU frame structure.

For each RRU, there are X UEs connected.

The fixed point test is assumed, where [20%] UEs are located at the good point, [60%] UEs located are at the medium point, and [20%] UEs are located at the bad point.

6.1.2.2.3.2 Latency Performance

The test is under Task 2.

Baseline: TDD configurations with the DDDSU frame structure.

For each RRU, there are X UEs connected.

The fixed point test is assumed, where [20%] UEs are located at the good point, [60%] UEs are located at the medium point, and [20%] UEs are located at the bad point.

6.1.2.2.3.3 Coverage Performance

The test is under Task 3.

Baseline: TDD configurations with the DDDSU frame structure.

The testing UE moves from the cell center to the cell edge, until the connection is lost.

6.1.2.2.4 Success Criteria

Compared with the legacy TDD, the sub-band non-overlapping full duplex operation may achieve the following gains.

1. Under Task 1, the enhancement of the system capacity and the reduced latency can be expected.

2. Under Task 2, more UEs can satisfy the latency requirement of the delay-sensitive traffic.

3. Under Task 3, the enhancement of the UL coverage can be expected.

6.2 Flexible Spectrum Access

6.2.1 Definition

Many operators have deployed or plan to deploy NR on more than two frequency bands with different bandwidths, the TDD/FDD duplex, and DL/UL configurations. In order to boost the uplink throughput and capacity for widely-applicable scenarios, it is necessary to utilize all uplink resources more efficiently in multi-carrier scenarios (> 2 bands) where most devices are smart phones with a limited number of Tx antennas (e.g. 2Tx).

6.2.2 Testing Environment

6.2.2.1 Testing Setup

One macro base station is configured with a number of spectrum bands for the uplink transmission, such as 4.9 GHz, 2.6 GHz, 2.3 GHz, and 700 MHz, available for the uplink transmission. Accordingly, one UE, which is capable of dynamically selecting 2 or 3 carriers out of these bands, is placed in several geographical locations to test the uplink user-perceived data rate.

In this test case, the testing will be done at the good, medium, and bad points. Take 2.6 GHz for example. The definition of the good, medium and bad points is:

- Good: RSRP ~-80 dBm;
- Medium: RSRP ~-90 dBm;
- Bad (at the cell edge): RSRP ~-100 dBm.

6.2.2.2 Testing Configuration

Table 37: The Test Configuration for the Flexible Spectrum Access

Attributes	Expect values
Carrier Frequency	Sub 6 GHz (such as 4.9 GHz, 2.6 GHz, and 2.3 GHz for CMCC) and sub 1 GHz (such as 700MHz for CMCC)
Aggregated System Bandwidth	Sub 6 GHz: 20 MHz; sub 1 GHz: 3.75 GHz
Sub-Carrier Spacing	Sub 6 GHz: 30 kHz; sub 1 GHz: 15KHz
Carrier Prefix (CP) Length	2.34 us for 30 kHz; 4.69 us for 15 kHz
Slot Length	0.5 milliseconds (14 symbol) for sub 6 GHz, and 1 millisecond for sub 1 GHz (700 MHz)
Number of Layers	Sub 6 GHz: up to 2 Layers; sub 1 GHz: up to 1 Layer
BS Antenna Elements	Sub 6 GHz: up to 64Tx and Rx antenna elements (for example, for 4.9 GHz and 2.6GHz) or up to 8 Rx antenna elements (for example, for 2.3GHz) Sub 1 GHz: up to 4 Rx antenna elements
UE Antenna Elements	Sub 6 GHz: up to 2 Tx antenna elements; sub 1 GHz: up to 1 Tx antenna element
User Location and Speed	100% outdoor (10 km/h)
Traffic Type	Full buffer traffic
Inter Site Distance	300 metres

6.2.2.3 Testing Procedures

In Rel-17 CA/SUL, an N-Tx UE (with N RF chains) can only be configured with 2 uplink bands. However, an N-Tx UE can be configured with 4 uplink bands with the Flexible Spectrum Access (FSA). Therefore, in the test, the Rel-17 CA/SUL baseline is that the best 2 uplink bands are semi-statically allocated to each UE via RRC reconfigurations, while with FSA, each UE can dynamically select the best 2 or 3 carriers from the configured 4 uplink bands per TTI-level.

1. Enable the R17 CA-SUL function and disable FSA. The UE is placed in the good points.

2. The UE is with the full buffer traffic. Start the test and record the UE uplink user-experience data rate. [6]

3. The UE is placed in the medium points. Repeat Step 2.

4. The UE is placed in the bad points. Repeat Step 2.

5. Enable FSA and disable the R17 CA-SUL. Repeat steps 1-4.

6.2.2.4 Success Criteria

Compared with R17, the uplink user-perceived data rate is increased up to 40% in different locations.

6.2.3 Reporting and Analysing Results

Table 38: The Reporting and Analysing Results for the Flexible Spectrum Access

Location	Uplink User-Experience Data Rate Using FSA (%)	Uplink User-Experience Data Rate Using R17 CA-SUL(%)
The Bad Points		
The Medium Points		
The Good Points		

6.3 Multi-Band Serving Cell

6.3.1 Definition

The existing CA mechanism treats each carrier as an independent serving cell and assumes that each carrier is managed and scheduled independently, which leads to unnecessary overheads, such as the downlink control channel. The multi-band serving cell (MB-SC) can combine the downlink control information (DCI) on multiple carriers, remove the redundant information, and use the single DCI to schedule multiple carriers/bands. The architecture of MB-SC is shown in Figure 21. The PDCCHs of three cells are merged into one control channel in one cell. CELL2 and CELL3 obtain the control signals from the PDCCH of CELL1, hence the PDCCH of CELL2 and CELL3 can be saved and their resources can be used for the PDSCH. Therefore, the control channels of the system are optimised, the overheads are reduced, as well as the spectrum efficiency is increased. At the same time, the power of the UE and the network can be saved.

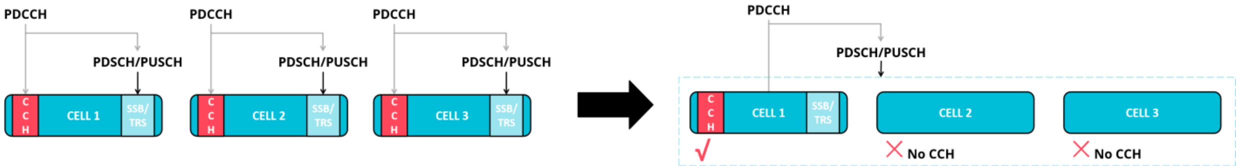


Figure 21: The Structure of the Multi-Band Serving Cell

6.3.2 Testing Environment

6.3.2.1 Testing Setup

A macro station is configured with two serving cells with the same coverage. The UE is configured to operate in the SA mode of the operation and communicates with the two cells. At the same time, 2-4 interfering sectors can be established.

In this test case, the test will be done at the good, medium, and bad points. Take 800 MHz and 900 MHz for example. The definition of the good, medium and bad points is:

- Good points: -40 dBm ≤ SSB RSRP < -55 dBm.
- Medium points: -55 dBm ≤ SSB RSRP < -75 dBm.
- Bad points: -75 dBm ≤ SSB RSRP ≤ -90 dBm.

6.3.2.2 Testing Configuration

The configuration is for NR FDD CA.

Table 39: The Testing Configuration for the Multi-Band Serving Cell

Attributes	Expected Values
Carrier Frequency	TDD/FDD band combinations (such as 700 MHz + 900 MHz for CMCC)
Aggregated System Bandwidth	10 MHz (For example: 5M for 700 MHz and 5M for 900MHz)
Sub-Carrier Spacing	15 kHz
Carrier Prefix (CP) Length	4.69 us
Slot Length	1 millisecond (14 symbols)
Number of Layers	up to 2 layers per carrier
BS Antenna Elements	2 Tx and 4 Rx antenna elements
UE Antenna Elements	1 Tx and 2 Rx antenna elements
User Location and Speed	100% outdoor (10 km/h)
Traffic Type	Full buffer traffic
Inter Site Distance	600 metres

6.3.2.3 Testing Procedures

1. Scenario 1: The static test
   1) Place the UE at the good, medium, and bad points respectively.
   2) Let the UE access CA cells with the full buffer traffic.
   3) Set the algorithm switch to the baseline (R16 FDD CA) and record the UE downlink throughput for several minutes (1-2 minutes without interference, while 5 minutes with interference).
   4) Change to MB-SC mode and record the UE downlink throughput again for the same

period.

5) Calculate the gain of MBSC with Formula (3).

$$\text{Gain} = \left(\frac{\text{the downlink throughput of MBSC}}{\text{the downlink throughput of baseline}} - 1\right) \times 100\%$$

(3)

6) Place the UE at the medium point, repeat steps 1)-5), then place the UE at the bad point and repeat steps 1) - 5) again.

2. Scenario 2: The driving test
    1) Place the UE in the testing vehicle and set the testing vehicle to the starting point of the test road. The test road should cover the good, medium, and bad points.
    2) Let UE access CA cells with the full buffer.
    3) Set the algorithm switch to the baseline (R16 FDD CA). Drive the vehicle from the starting point to the endpoint at the speed of 10 km/h.
    4) Do several tests and record the UE downlink throughput during the driving to calculate the average value.
    5) Change the mode from baseline to MB-SC and repeat steps 3) - 4).
    6) Plot the downlink throughput line of each test in the same figure, and calculate the gain of MBSC with Formula (3).

6.3.2.4 Success Criteria

MB-SC can achieve about 10% capacity gain compared with the legacy CA due to the overheads reduction.

6.3.3 Reporting and Analysing Results

Table 40: The Reporting and Analysing Results for the Multi-Band Serving Cell

		Baseline Downlink Throughput (Mb/s)	MBSC Downlink Throughput (Mb/s)	Throughput Gain (%)
Scenario 1	Good Points			
	Medium Points			
	Bad Points			
Scenario 2				

6.4 Higher Frequency

6.4.1 FR1 and FR2 NR Dual Connectivity

6.4.1.1 Definition

In the NR-NR dual connectivity with 5G Core, a UE is connected to one FR1-band gNB that acts as a Master Node (MN) and another FR2-band gNB that acts as a Secondary Node (SN).

MN and SN are connected to 5GC via the NG interface. MN is responsible for the control plane (NG-C) while the user plane (NG-U) terminates in SN. The UE is connected to both MN and SN through the Uu interface. MN and SN are connected through the Xn interface.

The User Plane data split is performed at the PDCP layer on the terminated Node.

Carrier Aggregation and Dual Connectivity can jointly be used. There may be multiple carriers in the Master cell group (MCG) and the Secondary Cell Group (SCG).

6.4.1.2 Testing Environment

6.4.1.2.1 Testing Setup

The UE under the test is located in the coverage area of both MCG and SCG.

MN cells are preferentially selected from FR1 while SN cells are configured as FR2.

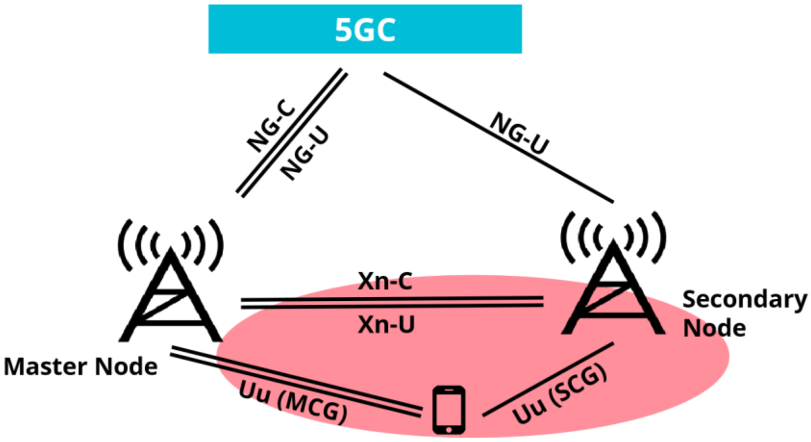


Figure 22: NR-NR DC Test Setup Overview

6.4.1.2.2 Test Configuration

1. The UE must be NR-DC capable.
2. MN is configured with the FR1 MCG cell (e.g. 100 MHz Cell BW on n78 band) or cells.
3. SN is configured with FR2 SCG cells (e.g. 8 mm-wave cells, each having 100 MHz cell bandwidth on n258 band).
4. The AMF in 5GC must support the NGAP procedure PDU Session Resource Modification.
5. Indicate and comply with 3GPP 38.413 v15.8.0 or later.

6.4.1.2.3 Test Procedures

1. The UE is located under the MCG coverage and registered to 5GC.

2. MN configures the UE about the FR2 PSCell measurements.

3. The UE enters the FR2-band coverage under SCG.

4. Measurement reports for SN are reported by the UE.

5. Observe that the SN addition procedure is initiated by MN over Xn, Uu, and NG interfaces as in Figure 23.

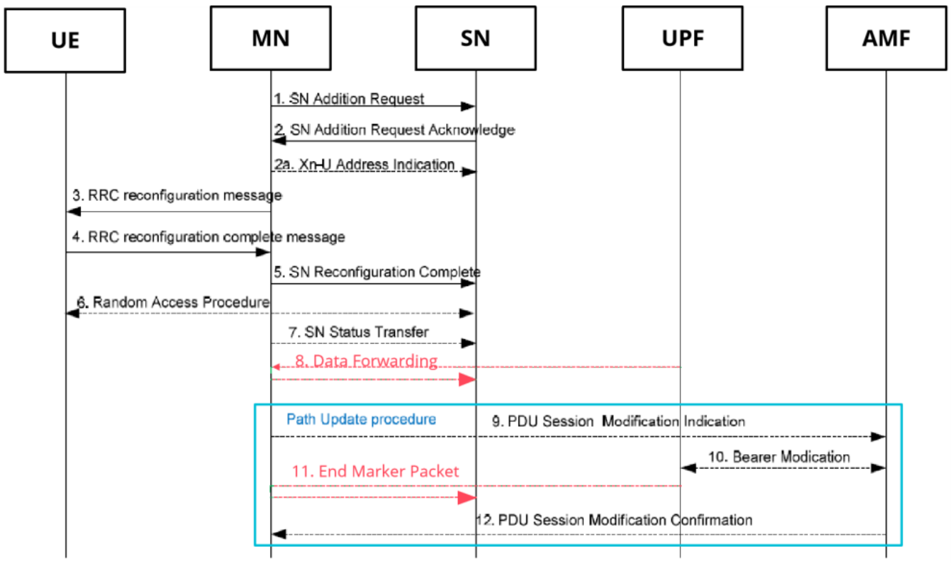


Figure 23: MR-DC with 5GC, SN Addition Procedure [5]

6. Make sure that the MCG and SCG signal level and quality are very good.

7. Start the downlink FTP or UDP test with the full buffer traffic.

8. Observe the DL throughput.

9. Start the uplink FTP or UDP test with the full buffer traffic.

10. Observe the UL throughput.

11. The UE moves out of the FR2 SCG coverage.

12. Observe that the SN Release procedure as in 3GPP 37.340 is initiated.

13. (Optional) Perform other test procedures covered by Section 10 in [5].

6.4.1.2.4 Success Criteria

1. In Step 5, observe that the SN addition procedure is completed.

2. In Step 8, observe the maximum achievable DL throughput. As an example, with the below configuration:
   1) One PCell having 100 MHz bandwidth n78 (4x4 MIMO, 256 QAM modulation, DDDSU slot configuration);
   2) Eight SCG cells each having 100 MHz bandwidth on n258 (2x2 MIMO, 64 QAM modulation, DDDSU slot configuration).

3. More than 5.5 Gbps DL throughput is expected.

4. In Step 10, observe the maximum achievable UL throughput.

5. (optional) In Step 13, observe that other test procedures covered by Section 10 in [5] are completed.

6.4.2 NR Carrier Aggregation

6.4.2.1 Definition

Carrier Aggregation can combine two or more channels in the same frequency band or between different frequency bands into a larger communication bandwidth to improve the uplink and downlink throughputs. Carrier Aggregation can efficiently utilize the scattered spectrums, achieve higher bandwidth through multiple carriers, improve the peak rate, and improve the network experience of users.

This is achieved by sending the user data simultaneously over multiple component carriers. These carriers may be either FDD and/or TDD and may cover multiple bands or bandwidths as dictated by the UE support and by 3GPP.

6.4.2.2 Testing Environment

6.4.2.2.1 Testing Setup

1. The intra-site setup:

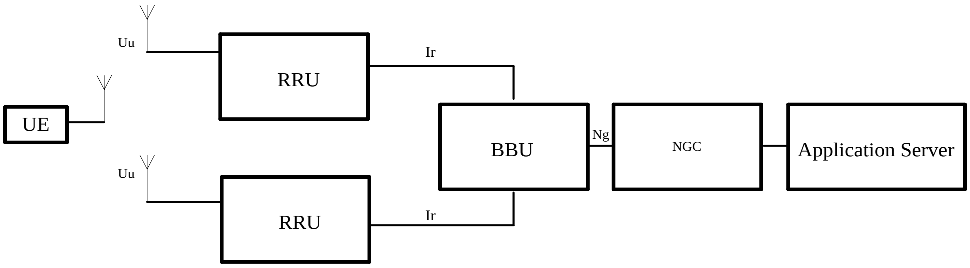


Figure 24: The Intra-Site Setup

2. The inter-site setup:

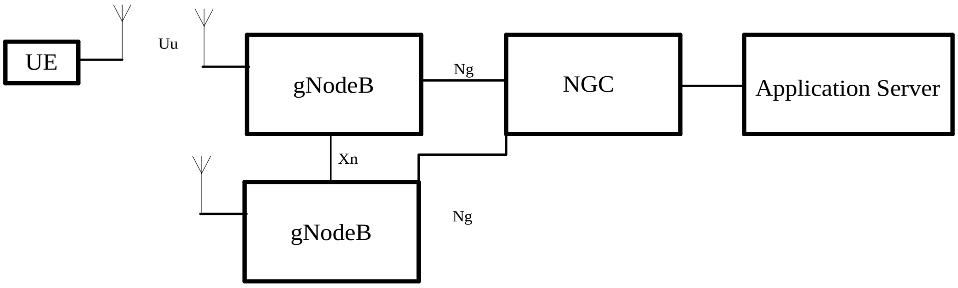


Figure 25: The Inter-Site Setup

The UE and the RAN shall support the NR CA combo in the test as dictated by supporting the software. TheBCS Combo shall be supported as stated in [2].

6.4.2.2.2 Testing Configuration

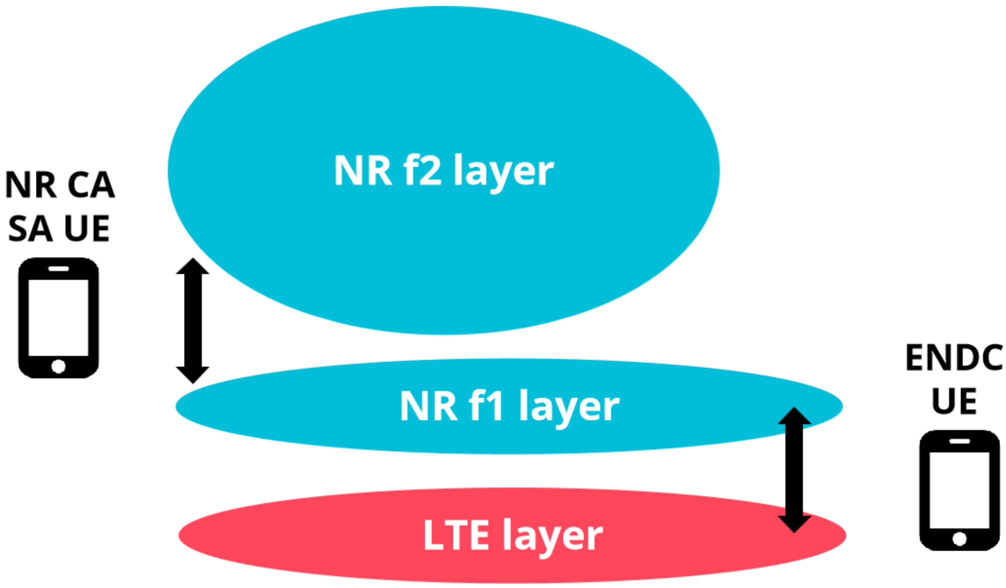


Figure 26: The NR CA Test Configuration

6.4.2.2.3 Testing Procedures

1. The blind/measurement-based addition of the SCell:
   1) Configure the carrier aggregation between NR f1 cell and NR f2 cells as per infra vendor documentation.

2) Power the testing UE and allow the UE to connect to the network via the 5G NR registration procedure.
3) Confirm the UE support of the combo in test as per the UE capability message.
4) Ensure the UE is camping on the appropriate PCell as per the combo in the test. This may be achieved by adjusting RF thresholds of the given PCell and SCell or by modifying cell re-selection priorities as provisioned in SIB/IMMCI information.
5) If the blind SCell addition is configured, skip to Step 8).
6) If the measurement-based SCell addition is provisioned, ensure the network configures the appropriate Ax Event in the measurement configuration located within the RRC Reconfiguration message.
7) Verify that the UE sends a measurement report of the cell, which satisfies the thresholds provisioned.
8) Verify that the Scell is added in the RRC Reconfiguration message located in the ScellToAddModList.
9) Perform the DL full buffer traffic and record the DL throughput.
10) Verify that the traffic is scheduled across both the PCell and SCell(s).

2. A2 Based SCell Removal:
   1) Configure the carrier aggregation between NR f1 cell and NR f2 cells as per infra vendor documentation.
   2) Power the testing UE and allow the UE to connect to the network via the 5G NR registration procedure.
   3) Verify that the SCell is added in the RRC Reconfiguration message located in the ScellToAddModList. Ensure that the SCell remains in the active state either by triggering.
   4) Move the UE out of the DL coverage of the SCell and verify that the UE sends the measurement report based on either the RSRP or the reference signal received quality (RSRQ), or both of them, corresponding to the insufficient DL coverage of the current SCell.

6.4.2.2.4 Success Criteria

1. Blind/Measurement-based addition of SCell
   1) Verify that the SCell is added in the RRC reconfiguration message located in the ScellToAddModList.
   2) Verify that traffic is scheduled across both the PCell and SCell(s).

2. A2 Based SCell Removal
   1) Verify the network configures the measurement for A2 SCell Removal as per configuration.
   2) Verify the measurement report is sent and the SCell is removed in the RRC Reconfiguration message located in the ScellRemoval List.
   3) Verify that the traffic is scheduled only on the PCell.

7 NEW APPLICATION ENABLER

7.1 High-Interactive Broadband Communication

The high-interactive broadband communication is considered one of the main features expected to be supported by the 5G-Advanced network to meet the stringent requirements of new emerging services such as eXtended Reality (XR) and Cloud Gaming (CG). Hence, some specific enhancements on the capacity and the UE power consumption should be needed and tested.

7.1.1 Capacity Evaluation

7.1.1.1 Definition

The capacity evaluation concentrates on the performance evaluation of the maximum number of satisfied UEs supported by a single cell. The capacity evaluation is also carried out by the introduction of some specific enhancements, and the capacity gain is expected compared to the baseline method.

The definitions of KPIs are given as follows [7]:

The UE satisfaction: a UE is declared as a satisfied UE if all the considered streams meet their requirements of the packet error rate (PER) and the packet delay budget (PDB), i.e. more than a certain percentage of packets are successfully transmitted within a given air interface PDB. Specifically, depending on the evaluation directions considered:

- In the DL-only evaluation, only DL streams are considered when identifying the UE satisfaction.
- In the UL-only evaluation, only UL streams are considered when identifying the UE satisfaction.

The system capacity: the system capacity is identified as the KPI for the capacity study, defined as the maximum number of users per cell with at least Y % of UEs being satisfied (as long as it satisfies the PDB and PER in the QoS feature, the UE is satisfied). For example, the XR service corresponds to the reference values of PDB and PER in the QoS flow stream. [7]

- Y=90 (baseline) or 95 (optional).
- Other values of Y can also be evaluated optionally.

7.1.1.2 Testing Environment

7.1.1.2.1 Testing Setup

Test the system capacity for a single cell of the 5G NR base station. UEs are uniformly distributed in the cell with the single connectivity, and each UE is only served by a single XR/CG service. The number of UEs needs to gradually increase after each test, to measure the maximum number of UEs supported by the cell as a measure of cell capacity.

7.1.1.2.2 Testing Configuration

This test is assumed to be applied to scenarios including the indoor hot spot scenario, the dense urban area, and the urban macro scenario.

Scenario-specific deployment attributes and expected values are listed in Table 2 for the indoor hot spot scenario, Table 3 for the dense urban area, and Table 4 for the urban macro scenario.

7.1.1.2.3 Testing Procedures

7.1.1.2.3.1 Baseline Method for Single-Stream Services Without any Potential Enhancement

1. Configure each UE to be served by a single-stream AR service with a data rate of 30 Mbps.

2. Start with one UE to be connected to the serving cell, and check whether the UE is satisfied.

3. If at least 90% of the connected UE(s) is/are satisfied, then add one more UE to be connected by the serving cell.

4. Repeat Step 3 until the UE satisfaction requirement cannot be met.

5. Measure the system capacity for the serving cell.

7.1.1.2.3.2 Baseline Method for Multi-Stream Services Without any Potential Enhancement

1. Configure each UE to be served by a multi-stream AR service (two streams with one I-frame stream and one P-frame stream) with a data rate of 30 Mbps.

2. Start with one UE to be connected to the serving cell, and check whether the UE is satisfied.
3. If at least 90% of the connected UE(s) is/are satisfied, then add one more UE to be connected by the serving cell.
4. Repeat Step 3 until the UE satisfaction requirement cannot be met, and repeat the above procedure 20 times.
5. Measure the system capacity for the serving cell.

7.1.1.2.3.3 **Cell Capacity Delay Aware Scheduler**

As indicated in [7], this section tests the capacity performance with the enhancement on gNB with the Delay Aware Scheduler relative to the typical per frame (PF) scheduler.

The Delay Aware Scheduler: during the scheduling, the gNB considers factors including the remaining delivery time of the frame, etc.

The test procedure is similar to Section 7.1.1.2.3.1.

7.1.1.2.3.4 **Frame Level Integrated Transmission Scheduler**

As indicated in [7], this section tests the capacity performance with the enhancement on gNB with the Frame Level Integrated Transmission (FLIT) Scheduler relative to the typical PF scheduler.

The FLIT Scheduler: During the scheduling, the gNB considers factors including the size of the frame, the size of the already sent part of the frame, the remaining delivery time of the frame, etc.

The test procedure is similar to Section 7.1.1.2.3.1.

7.1.1.2.3.5 **gNB Scheduling Awareness UE Playout Buffer**

As indicated in [7], the playout buffer at UE would ensure the in-sequence and the time interval alignment of XR video frames when it plays out to the user. The proposed scheme is for the UE to feedback not only on the XR-application type (the XR-application awareness) but also on the implemented playout buffer at the application layer to the gNB.

In the evaluation, the size of the playout buffer is feedback from the UE and known at the gNB. Then the gNB can have additional PDB, which could give the gNB more time to schedule the UE within the delay budget requirements of the XR service and more likely to successfully transmit packets with the link adaptation gain. The gNB knowing the size of the playout buffer can preferentially schedule the UE with the packet delay close to the deadline and better channel conditions.

The test procedure is similar to Section 7.1.1.2.3.1.

7.1.1.2.3.6 **Prioritizing Important Stream**

As indicated in [7], this section tests the capacity performance by prioritizing important streams.

In the evaluation, the transmission of the more important stream, e.g. I-frame or pose/control is prioritized.

The test procedure is similar to Section 7.1.1.2.3.2.

7.1.1.2.3.7 **HARQ-ACK Enhancement for DG Scheduling**

As indicated by [7], this section tests the capacity performance with the HARQ-ACK enhancement for the DG scheduling. In the evaluation, the soft HARQ-ACK is used, where the UE provides enhanced the HARQ-ACK feedback beyond the baseline single bit ACK/NACK status in the form of a Delta MCS based on PDSCH decoding.

The test procedure is similar to Section 7.1.1.2.3.1.

7.1.1.2.3.8 **Enhanced Buffer Status Reporting for UL Transmission**

As indicated by [7], this section tests the capacity performance with enhanced BSR for UL transmission.

The test procedure is similar to Section 7.1.1.2.3.1.

7.1.1.2.4 Success Criteria

The potential enhancements are expected to improve the system capacity compared to the baseline method.

7.1.1.3 Reporting and Analysing Results

Table 41: The Reporting and Analysing Results for the Capacity Evaluation

Indicator	Baseline Single-Stream	Baseline Multi-Stream	Delay Aware Scheduler	Frame Aware Scheduler	UE Buffer Awareness	Stream Prioritization	Enhanced HARQ	Enhanced BSR
System Capacity								

7.1.2 UE Power Consumption Evaluation

7.1.2.1 Definition

The UE power consumption evaluation concentrates on the performance evaluation of the power saving gain (PSG) by the introduction of the specific UE power saving schemes for a single cell.

Different UE power saving schemes consist of (as indicated by [7]):

- AlwaysOn: in this scheme, the UE is always available for the scheduling (i.e., no DRX off period). When the UE is not receiving/transmitting DL/UL data, the UE is assumed to keep monitoring the PDCCH.
- R15/16 CDRX: the connected mode DRX scheme is assumed.
- Enhancement of CDRX: the enhancement on R15/16 CDRX is to satisfy the non-integer periodicity for XR/CG services.
- Cross-slot scheduling and MIMO layer adaptation by BWP switching: The R16 dynamic BWP switching across different BWP with different configurations of minimum K0 and maximum MIMO layers.
- R17 PDCCH monitoring adaptation: the UE skipping PDCCH monitoring based on a dynamically indicated the PDCCH skipping indication and/or the search space set group switching (SSSG) indication. In this scheme, it is assumed that the network will send the PDCCH skipping command with sthe kipping duration(s) (In detail, the described operation may or may not be fully compliant with the R17 PDCCH monitoring adaptation scheme which is currently still being discussed in R17 UE PS session as of 107-e).
- Genie: in this scheme, the UE is assumed to be in a sleep state (e.g., micro/light/deep sleep as defined in [8]) whenever there is neither DL data reception nor UL transmission.

The definitions of KPI are given as follows [7].

The power-saving gain (PSG) is determined from A, the power consumption of a power-saving scheme, and B, the power consumption of the baseline (AlwaysOn) case; PSG = (B-A)/B×100%. Since the UE power saving gain typically comes with the capacity loss (i.e., more precisely, the loss in the satisfied UE ratio), it also needs to be considered jointly with the power consumption/power saving gain.

7.1.2.2 Testing Environment

7.1.2.2.1 Testing Setup

A 5G NR base station is configured with a single cell. A single UE located at the good/medium/bad points is tested under the low/high cell load.

7.1.2.2.2 Testing Configuration

This test is assumed to be applied to scenarios including the indoor hot spot scenario, the dense urban area, and the urban macro scenario.

Scenario-specific deployment attributes and expected values are listed in Table 2 for the indoor hot spot scenario, Table 3 for the dense urban area, and Table 4 for the urban macro scenario.

7.1.2.2.3 Testing Procedures

1. Configure the testing UE to be served by a single-stream AR service with a data rate of 30 Mbps at a good point.

2. Configure the UE to be in the AlwaysOn mode, and measure the average power consumption over a period of time.

3. Introduce the power saving enhancement (R15/16 CDRX, Enhancement of CDRX, dynamic BWP switching, R17 PDCCH monitoring adaptation, and Genie) one at a time, measure the average power consumption over a period of time, and calculate the PSG by each enhancement compared to the AlwaysOn mode.

4. Repeat steps 1-3 in both low and high cell load scenarios in both FR1 and FR2.

5. Repeat steps 1-4 at the medium and bad points.

7.1.2.2.4 Success Criteria

The potential enhancements are expected to achieve a PSG of y compared to the AlwaysOn mode.

7.1.2.3 Reporting and Analysing Results

Table 42: The Reporting and Analysing Results for the UE Power Consumption Evaluation

	Indicator	AlwaysOn	R15/16 CDRX	Enhanced CDRX	Dynamic BWP Switching	R17 PDCCH Monitoring Adaptation	Genie
Good points	PSG with Low Load in FR1						
	PSG with Low Load in FR2						
	PSG with High Load in FR1						
	PSG with High Load in FR2						
Medium points	PSG with Low Load in FR1						
	PSG with Low Load in FR2						

	PSG with High Load in FR1						
	PSG with High Load in FR2						
Bad points	PSG with Low Load in FR1						
	PSG with Low Load in FR2						
	PSG with High Load in FR1						
	PSG with High Load in FR2						

7.2 Positioning and Sensing Evolution

7.2.1 5G Precise Positioning Solution

Industrial customers require the precise indoor positioning with the low latency and the ultra-reliable positioning to be able to support their industry 4.0 use cases (e.g. flexible manufacturing). The 5G precise positioning is a key component of the industrial IoT scenario.

The 5G precise positioning is based on the 5G gNB analysis of the UE UL SRS signal (UL SRS defined in R15 [9] and R16 [10]) per pico remote radio head (pRRH)/sub-cell per antenna path.

- The Time of Arrival (ToA) of the UL SRS signal is compared between different antenna paths within one pRRH and cross pRRHs within one supercell to get an accurate ToA difference matrix in the coverage area.
- The UL SRS signal phase difference is measured by the antenna array of each pRRH to get UE's angle to each pRRH. Multiple AoA measurement results cross pRRHs within one supercell, the AoA matrix, provide specific UE position reference information.

The gNB provides UE UL SRS measurement results, the ToA difference matrix and the AoA matrix, to the location management function (LMF) via the NR positioning protocol A (NRPPa) signal message. LMF, with the specific pRRHs location information, can make a combined calculation based on UE UL SRS measurement results to obtain a more accurate UE position.

However, the position obtained by the above-mentioned methods can be influenced by the environment, such as the temperature. Therefore, as an option, UL SRS measurement results of the reference UE, a normal 5G UE at a known position, can be used for further calibration. LMF will utilize the difference between the calculated position and the real position of the reference UE to adjust the position results of target UEs.

7.2.1.1 Definition

The solution architecture based on the 5G small cell BTS has been jointly combining the UTDoA with the nanosecond synchronization and AoA methods with the goal of achieving a precision of 3 metres defined in Release 16.

7.2.1.2 Testing Environment

7.2.1.2.1 Testing Setup

The UE and the small cell BTS are configured to operate in 5G SA mode.

7.2.1.2.2 Testing Configuration

The BS and UE antenna elements are up to 4 Tx and Rx antenna elements for sub 6 GHz.

The inter site distance is recommended to be 10-50 metres, depending on the scenario.

Other scenario-specific deployment attributes and expected values are listed in Table 2 for the indoor hot spot scenario, only applying the parameters for sub 6 GHz.

7.2.1.2.3 Testing Procedures

1. The test 5G UE sends a UL SRS message to all the 5G locators (the pRRHs serve in the position calculation of UL SRS receiving). The UE position is known before the test.
    1) The UE is placed in a test location of the good point. The good point means that there is a line of sight (LOS) between the test UE and more than three locators.
    2) The UE is placed in a test location corresponding to the bad point. The bad point means that there is a LOS between the test UE and only one locator, or the obstruction exists between the UE and any locator.

2. All 5G locators listen to the UL SRS message from the testing UE, and measure at least one of two quantities: ToA and AoA.

3. The ToA and/or the AoA measured at all 5G locators are sent to the LMF for calculating the UE position using the UTDoA (uplink time difference of arrival) and/or the AoA triangulation. Compare the calculation results with the known location data.

7.2.1.2.4 Success Criteria

Expected RAW results: 50 cm @50%, < 3 m in 80% of the cases.

7.2.1.3 Reporting and Analysing Results

Table 43: The Reporting and Analysing Results for the 5G Precise Positioning Solution

Location	ToA	AoA	The Calculated UE position
The Good Point			
The Bad Point			

7.2.2 Harmonised Communication and Sensing

The sensing will be the basic requirement of the intelligent society, such as intelligent transports, the intelligent safety guarding of unmanned aerial vehicles (UAV), the intelligent elder healthcare, etc.

The 5G device has the natural sensing capability and technical advantages in terms of the widely deployed network architecture, the strong coverage capability, the wide-bandwidth spectrum, and large-scale antenna arrays. Through software and hardware upgrades, the 5G network can meet communication and sensing requirements simultaneously.

7.2.2.1 Definition

To support the sensing capability, a conventional cellular communication system is reused. The Signal Transmitting and Receiving Unit transmits the sensing signal, receives and processes the reflection signal from surrounding objects; a few slots, such as 10% slots, are used for the sensing while other slots are used for the communication as usual.

The harmonised communication and sensing network architecture is shown in Figure 27. The Target Information Computing Unit supports sensing the target information computing, e.g. the position, the velocity, and the size. The information will be reported to the application platform to generate the event information, such as the UAV invading warning.

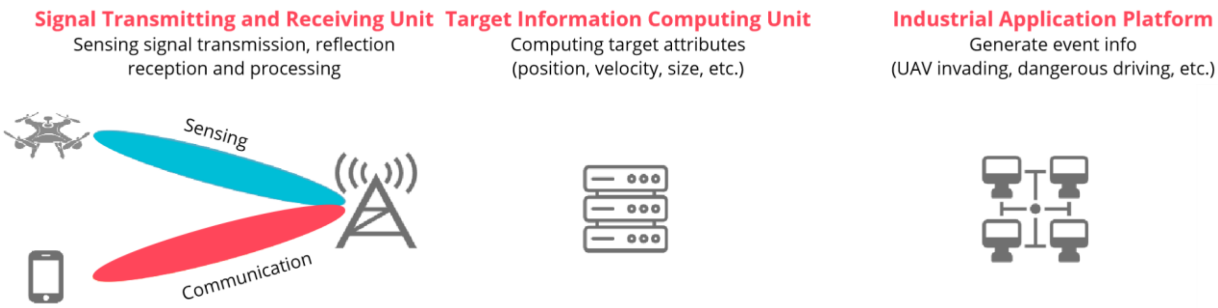


Figure 27: The Harmonised Communication and Sensing Network Architecture

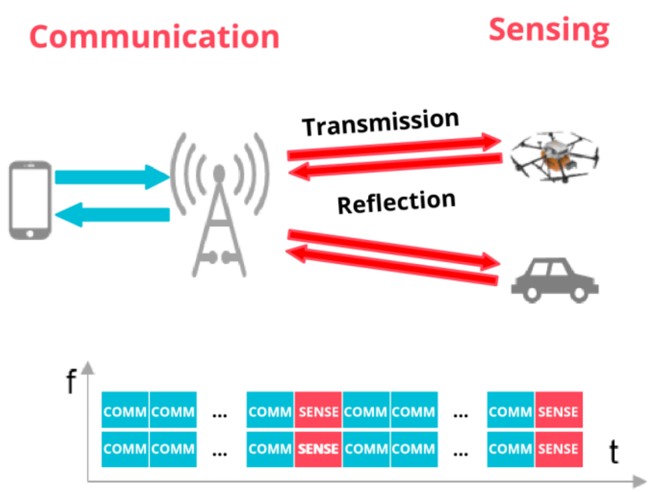


Figure 28: RAN Sensing Framework

7.2.2.2 Testing Environment

7.2.2.2.1 Testing Setup

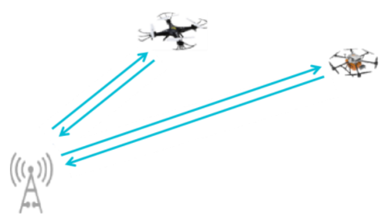


Figure 29: The Testing Setup with the BS and the Flying Objects

One base station is placed on the top of the building. Drones fly in the air, to be detected by the base station, as shown in Figure 29.

7.2.2.2.2 Testing Configuration

Table 44: The Testing Configuration for the Harmonised Communication and Sensing

Attributes	Expected Values
Carrier Frequency	Above 6 GHz (such as 26 GHz)
Aggregated System Bandwidth	400 MHz

Sub-Carrier Spacing	120 kHz
Carrier Prefix (CP) Length	0.59 us
Slot Length	0.125 ms (14 symbols)
BS Antenna Elements	Up to 384 Tx and Rx antenna elements
User Location and Speed	Outdoor UAV (30 km/h)

7.2.2.2.3 Testing Procedures

7.2.2.2.3.1 Sensing Coverage

1. Turn on the sensing function for the base station.
2. Configure a drone to fly gradually far away from the coverage of the base station.
3. Test 3 times and observe the track of the drone detected by the base station.
4. Record the maximum distance that the drone can be detected in the three tests, which is the sensing coverage.

7.2.2.2.3.2 Height & Position Precision

1. Turn on the sensing function for the base station.
2. Configure a drone to fly according to a pre-configured trajectory.
3. Record the trajectory of the flying drone as detected by the base station.
4. Compare it with the actual trajectory according to a GNSS system.

5. Calculate the drone's height and horizontal position difference between the two trajectories. The average values of the differences mentioned above at different time are referred to as the height precision and the position precision, respectively.

7.2.2.2.4 Success Criteria

The sensing coverage > 500 metres, the height precision <10 metres, and the position precision < 20 metres.

7.2.2.3 Reporting and Analysing Results

Table 45: The Reporting and Analysing Results for the Harmonised Communication and Sensing

The sensing coverage	The height precision	The position precision

7.3 Passive IoT

The number of internet-of-things (IoT) connections has been growing rapidly in recent years and is predicted to be hundreds of billions by 2030 [11]. With more and more 'things' expected to be interconnected for improving the production efficiency and increasing the comfort of life, it demands further reduction of the size, the cost, and the power consumption for IoT devices. In particular, the regular replacement of batteries for all IoT devices is impractical due to the tremendous consumption of materials and the manpower. It has become a trend to use the energy harvested from environments to power IoT devices for self-sustainable communications, especially in applications with a huge amount of devices (e.g., ID tags and sensors). The widely used radio frequency identification (RFID) solution has shown the drawbacks of the poor coverage and the strong self-interference, and it is hard to support the sensing ability. A passive IoT system is a battery-free and low-cost solution that supports the ubiquitous IoT node deployment. There are two typical use cases for Passive IoT: the ID identification and the sensing. In the former case, the information (e.g. identity) is pre-stored in a small-size, ultra-low-cost, and battery-less tag. The ID information is collected by reader devices. The latter is to report the sensor data such as the temperature, the humidity, etc.

7.3.1 Definition

The Passive IoT system consists of a Passive IoT reader and several Passive IoT tags. The tag transmits the stored information, which is the identity, and potentially the sensing status of the tag on the object when it detects the downlink signal from the reader.

7.3.2 Testing Environment

7.3.2.1 Testing Setup

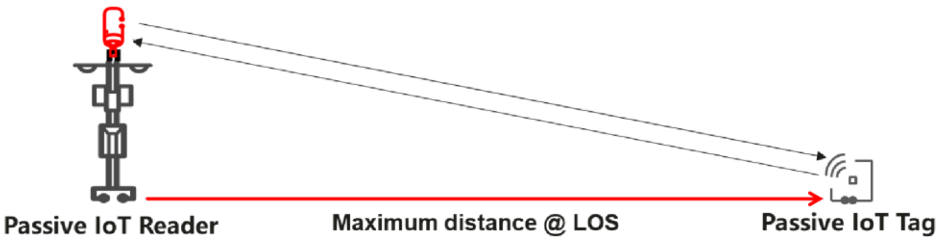


Figure 30: The Testing Setup for Passive IoT

The Passive IoT test setup consists of a Passive IoT reader and a Passive IoT tag. The Passive IoT reader is powered by a 48 V direct-current power supply, while the Passive IoT tag is powered by the new energy, such as a solar panel, and works without a battery. There exists a LOS path between the reader and the tag.

7.3.2.2 Testing Configuration

The height of both the Passive IoT reader and the Passive IoT tag are higher than 4 metres (the typical height of pole site) and about 1.5 metres (the typical height of UE), respectively, and the equivalent isotropically radiated power (EIRP) of the Passive IoT reader is 46 dBm. The height of both the RFID reader and the RFID tag are about 1.5 metres, and the EIRP of the RFID reader is 36 dBm. The downlink physical layer parameters of Passive IoT are compatible with 5G to support the smooth evolution of the cellular infrastructure. The RFID system is independent of the cellular system, which has no definition of OFDM-related parameters. Table 46 lists the reference configuration for the testing of the Passive IoT.

Table 46: The Testing Configuration for the Passive IoT

Attributes	Expected Values	
System	Passive IoT	RFID
Carrier Frequency	Sub 1 GHz	Sub 1 GHz
Aggregated System Bandwidth	180 kHz	180 kHz
Sub-Carrier Spacing	15 kHz	N/A
Cyclic prefix (CP) Length	4.69 us	N/A
Slot Length	1 ms	N/A
Number of Layers	1	N/A
Reader Antenna Elements	1 Tx and 2 Rx antenna elements	1 Tx and 1 Rx antenna elements
Tag Antenna Elements	1 Tx and 1 Rx antenna elements	1 Tx and 1 Rx antenna elements
User Location and Speed	100% Outdoor, 0 km/h	100% Outdoor, 0 km/h
Traffic Type	N/A	N/A
Inter Site Distance	N/A	N/A

7.3.2.3 Testing Procedures

1. Configure the Passive IoT reader transmissions @46 dBm EIRP and the Passive IoT reader to collect the ID and temperature sensor data of the Passive IoT tag.

2. Set the initial distance between the Passive IoT reader and the Passive IoT tag to be 50 metres.

3. Increase the distance between the Passive IoT reader and the Passive IoT tag until the tag cannot be identified, and record the current distance as the maximum coverage of the Passive IoT.

4. Set a commercial RFID tag at a fixed location, and use a handheld RFID reader to read the tag information with the maximum transmitting power.

5. Set the initial distance between the RFID reader and the RFID tag as 3 metres.

6. Increase the distance between the RFID reader and the RFID tag until the tag cannot be identified, and record the current distance as the maximum coverage of RFID.

7.3.2.4 Success Criteria

The ID information and the temperature sensor data of the Passive IoT tag can be collected by the reader within the range of 150 metres (considering the typical pole site deployment distance is 300 metres), which is the minimum requirement of the maximum coverage radius under the LOS environment.

7.3.3 Reporting and Analysing Results

Table 47: The Reporting and Analysing Results for the Passive IoT

	Coverage (metres)	Acquisition of Sensor Data
Passive IoT		
RFID		

LIST OF ABBREVIATIONS

3GPP	Third Generation Partnership Project
5G	5th Generation Mobile Communication Technology
5GC	5G core
5QI	5G QoS Identifier
AAU	Active antenna unit
ADC	Analog-to-digital converter
AI	Artificial intelligence
AMC	Adaptive modulation and coding
AoA	Angle of arrival
API	Application programming interface
AR	Augmented reality
ARMA	Auto regressive moving average
BBU	Building baseband unit
BLER	Block error rate
BS	Base station
BTS	Base transceiver station
BSR	Buffer status report
BWP	Bandwidth part
CA	Carrier aggregation
CDRX	Connectedmode DRX
CG	Cloud gaming
CLI	Cross link interference
CN	Core network
CP	Carrier prefix
CQT	Call quality test
CSI	Channel state information
CSI-RS	Channel state information reference signal

DC	Dual connectivity
DCI	Downlink control information
DL	Downlink
DMRS	Demodulation reference signal
DRX	Discontinuous reception
DSS	Dynamic Spectrum sharing
DT	Driving test
e2e	End-to-end
EE	Energy efficiency
EIRP	Equivalent isotropically radiated power
eMBB	enhanced mobile broadband
FDD	Frequency division duplex
FLIT	Frame level integrated transmission
FNR	FDD New Radio
FSA	Flexible spectrum access
gNB	5G NodeB
GNSS	Global navigation satellite system
GPS	Global positioning system
HCS	Harmonized communication and sensing
IMS	IP multimedia subsystem
IoT	Internet of things
IP	Internet protocol
LMF	Location management function
LOS	Line of sight
LSE	Large smart engine
LSTM	Long-short term memory
LTE	Long term evolution
MCG	Master cell group
MCS	Modulation and coding scheme

MIMO	Multiple input multiple output
ML	Machine learning
mMTC	massive machine type communication
MN	Master node
MOS	Mean opinion score
MR	Measurement report
MU	Multi-user
NGAP	NG Application Protocol
NGMN	Next Generation Mobile Networks
NR	New radio
NRPPa	NR Positioning Protocol A
NSA	Non-standalone
NSSAI	Network Slice Selection Assistance Information
OMC	Operation and maintenance center
PF	Per frame
Pcell	Primary cell
PER	Packet error rate
PDB	Packet delay budget
PDCCH	Physical downlink control channel
PDCP	Packet Data Convergence Protocol
PDSCH	Physical downlink shared channel
PER	Power efficiency ratio
PoC	Proof of concept
PRB	Physical resource block
pRRH	Pico remote radio head
PSG	Power saving gain
PSS	Primary synchronization signal
PUCCH	Physical uplink control channel
PUSCH	Physical uplink shared channel

QoE	Quality of experience
QoS	Quality of service
RAN	Radio access network
RAT	Radio access technology
RB	Resource block
RF	Radio frequency
RFID	Radio frequency identification
RIC	RAN intelligent controller
RIM	Remote interference management
RLC	Radio link control
RMSI	Remaining minimum system information
RNN	Recurrent neural network
RRC	Radio resource control
RRU	Remote radio unit
RSE	Real-time smart engine
RSRP	Reference signal received power
RSRQ	Reference signal received quality
RTP	Real-Time Transport Protocol
RTT	Round trip time
Rx	Receiving
SA	Standalone
Scell	Secondary cell
SCG	Secondary cell group
SDU	Service data unit
SE	Spectrum efficiency
SI	Self-interference
SINR	Signal to interference and noise ratio
SN	Secondary node
SNR	Signal to noise ratio

SRS	Sounding reference signal
SSB	Single side band
SSS	Secondary synchronization signal
SSSG	Search space set group
SU	Single user
TCP	Transmission control protocol
TDD	Time division duplex
ToA	Time of arrival
Tx	Transmitting
UAV	Unmanned aerial vehicle
UDP	User datagram protocol
UE	User equipment
UL	Uplink
URLLC	Ultra-reliable low-latency communications
UTDoA	Uplink time difference of arrival
VR	Virtual reality
XR	eXtended Reality

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