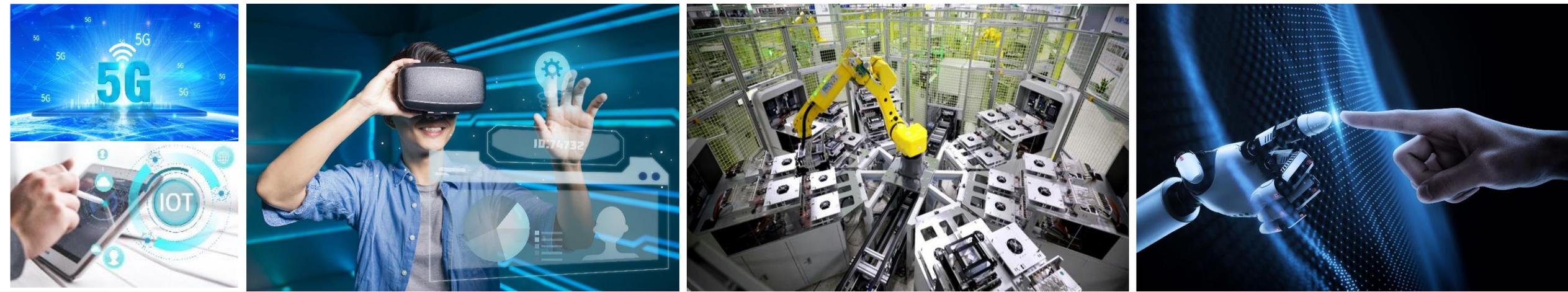


Taipei, June 15 - 16, 2023

Agenda item: 5



Views on evolution of NR duplex operation in Rel-19

目录

CONTENTS

01

Background

02

Simulation & Prototypes of SBFD

03

Summary and Draft Objective

Background: Motivation for SBFD

High uplink requirement for HD video and XR



Video 1080P

- BW 5Mbps
- Latency 100ms



Video 4K

- BW 25Mbps
- Latency 100ms



Online game

High fidelity, strong interaction

>100Mbps, <20ms



XR

High fidelity, less interaction

>100Mbps, >150ms

Performance assurance is one of main challenges for vertical



HD Machine Vision

- BW >50Mbps
- Latency 20ms



Ultra-HD 3D Machine Vision

- BW >200Mbps
- Latency 5-10ms



Remote Control

- BW >50Mbps
- Connectivity 1~2
- Latency 20ms@99.99%



Ultra-dense remote control

- BW >200Mbps
- Connectivity >10
- Latency 10-15ms@99.999%

Diverse requirement for sensing, remote control and smart industry



Intelligent manufacturing



Smart Steel Industry

Main services

- Machine vision quality inspection
- Panoramic monitoring of production line
- AGV coordination
- Cloud PLC

- Remote control of crown block
- Unmanned driving
- Panoramic monitoring
- Machine vision inspection of steel strip surface

Throughput

> 300Mbps

> 300Mbps

Latency

< 10ms@99.999%

Control command
< 20ms@99.999%

Scenarios

Outdoor

Outdoor & Indoor

SBFD addresses the challenge of supporting both high UL throughput traffic and high reliability traffic in the same cell.

Background: Study item in 3GPP

The objective of this study is to identify and evaluate the potential enhancements to support duplex evolution for NR TDD in unpaired spectrum.

In this study, the followings are assumed:

- Duplex enhancement at the gNB side
- Half duplex operation at the UE side
- No restriction on frequency ranges

The detailed objectives are as follows:

- Identify applicable and relevant deployment scenarios (RAN1).
- Develop evaluation methodology for duplex enhancement (RAN1).
- Study the subband non-overlapping full duplex and potential enhancements on dynamic/flexible TDD (RAN1, RAN4).
 - Identify possible schemes and evaluate their feasibility and performances (RAN1).
 - Study inter-gNB and inter-UE CLI handling and identify solutions to manage them (RAN1).
Consider intra-subband CLI and inter-subband CLI in case of the subband non-overlapping full duplex.
 - Study the performance of the identified schemes as well as the impact on legacy operation assuming their co-existence in co-channel and adjacent channels (RAN1).
 - Study the feasibility of and impact on RF requirements considering adjacent-channel co-existence with the legacy operation (RAN4).
 - Study the feasibility of and impact on RF requirements considering the self-interference, the inter-subband CLI, and the inter-operator CLI at gNB and the inter-subband CLI and inter-operator CLI at UE (RAN4).
 - Note: RAN4 should be involved early to provide necessary information to RAN1 as needed and to study the feasibility aspects due to high impact in antenna/RF and algorithm design, which include antenna isolation, TX IM suppression in the RX part, filtering and digital interference suppression.
 - Summarize the regulatory aspects that have to be considered for deploying the identified duplex enhancements in TDD unpaired spectrum (RAN4).

Note: For potential enhancements on dynamic/flexible TDD, utilize the outcome of discussion in Rel-15 and Rel-16 while avoiding the repetition of the same discussion.

Background: Overall progress

- Both SBFD and dynamic TDD have been studied in Rel-18, including simulation assumptions & results, SBFD framework & operation, CLI (Cross Link Interference) handling schemes.
- Overall, good progress has been achieved for both SBFD and dynamic TDD.
- Lots of companies have submitted simulation results to 3GPP, i.e., [https://www.3gpp.org/ftp/tsg_ran/WG1_RL1/TSGR1_112/Inbox/drafts/9.3\(FS_NR_duplex_evo\)/9.3.1/Evaluation%20Results/](https://www.3gpp.org/ftp/tsg_ran/WG1_RL1/TSGR1_112/Inbox/drafts/9.3(FS_NR_duplex_evo)/9.3.1/Evaluation%20Results/)
- Some initial observations have been drawn for SBFD for indoor scenarios in TR 38858, which show gain for SBFD.

目录

CONTENTS

01

Background

02

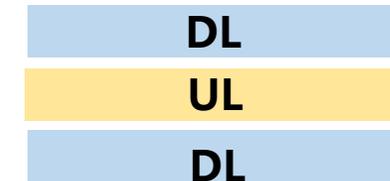
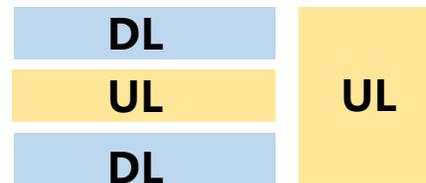
Simulation & Prototypes of SBFD

03

Summary and Draft Objective

Simulation assumptions

- Scenarios: Indoor, Dense Urban Macro
- Metrics: DL/UL average UP (mean, 5%, 50%, 95%)
- Frequency and bandwidth: 4GHz, 100MHz bandwidth
- Packet size:
 - Large packet size: DL/UL packet size = 0.5M /0.125M bytes, longer transmission duration, stronger interference
 - Small packet size: DL/UL packet size = 5K/1K bytes, shorter transmission duration, smaller interference
- Interference models: gNB self-interference, inter-gNB inter-subband interference, co-cite inter-sector interference, inter-UE inter-subband interference
- DL/UL resource partition
 - Legacy TDD: DDDSU, 77.14% DL resource, 20% UL resource,
 - Sbfd:
 - Sbfd Alt.2: XXXXU, X applies “DUD” pattern, 59.86% DL resource, 35.83% resource
Note: Compared with Legacy TDD, DL resource of Sbfd Alt.2 is decreased by 22%, UL resource is increased by 79%
 - Sbfd Alt.4: XXXXX, X applies “DUD” pattern, 76.19% DL resource, 20.15% UL resource
Note: DL/UL resource ratio of Sbfd are almost the same as Legacy TDD.



Note: More detailed simulation assumptions in the appendix.

Simulation Results & observations

Indoor hotspot			Low traffic load		Medium traffic load		High traffic load	
			Cell-edge UE	Cell-center UE	Cell-edge UE	Cell-center UE	Cell-edge UE	Cell-center UE
SBFD Alt.2 (XXXXU)	Small Packet	DL	—	—	—	—	↓	—
		UL	↑↑↑	↑↑↑	↑↑↑	↑↑↑	↑↑↑	↑↑↑
	Large Packet	DL	↓	↓	↓	↓	↓↓	↓
		UL	—	↑↑	↑	↑↑	↑↑	↑↑
SBFD Alt.4 (XXXXX)	Small Packet	DL	↑	↑	↑	↑	↑	↑
		UL	↑↑↑	↑↑↑	↑↑↑	↑↑↑	↑↑↑	↑↑↑
	Large Packet	DL	—	—	—	—	↓↓	—
		UL	—	↑	↑	↑	↓	↑

— UPT is almost the same, i.e., -10% ~ 10%.

↑ UPT is increased. The more arrows, the higher gain, i.e., ↑ 10% ~ 30%, ↑↑ 30% ~ 90%, ↑↑↑ > 90%

↓ UPT is decreased. The more arrows, the higher loss, i.e., ↓ 10% ~ 30%, ↓↓ 30% ~ 90%, ↓↓↓ > 90%

Simulation Results & observations

Dense Urban Macro Layer			Low traffic load		Medium traffic load		High traffic load	
			Cell-edge UE	Cell-center UE	Cell-edge UE	Cell-center UE	Cell-edge UE	Cell-center UE
SBFD Alt.2 (XXXXU)	Small Packet	DL	—	—	—	—	↓↓↓	—
		UL	↑↑↑	↑↑↑	↑↑↑	↑↑↑	↑↑	↑↑↑
	Large Packet	DL	↓	↓	↓↓	↓	↓↓↓	↓
		UL	—	↑↑	—	↑↑	—	↑↑
SBFD Alt.4 (XXXXX)	Small Packet	DL	—	—	—	—	↓	—
		UL	—	↑↑↑	—	↑↑↑	—	↑↑↑
	Large Packet	DL	—	—	—	—	—	—
		UL	↑	—	↑	↑	↑	↑

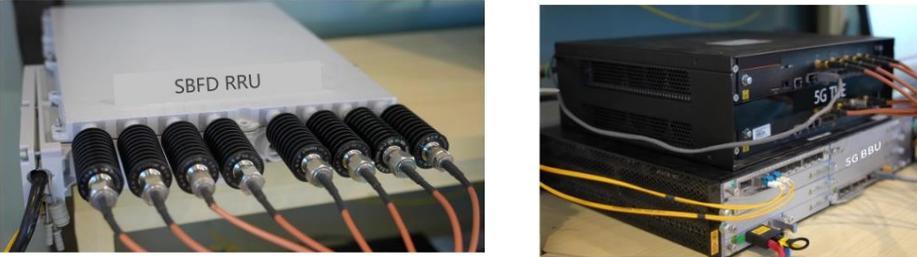
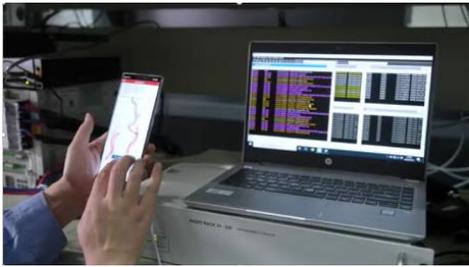
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↓ UPT is decreased. The more arrows, the higher loss, i.e., ↓ 10% ~ 30%, ↓↓ 30% ~ 90%, ↓↓↓ > 90%

Prototypes of SBFD

- Two SBFD BS prototypes are researched and verified by ZTE and CMCC collaboratively in CMCC's 5G-A Innovation Lab.
 - The 1st SBFD prototype is researched to verify the feasibility and evaluate the actual performance of SBFD operation with test UE (TUE).
 - The 2nd SBFD prototype is researched to verify the compatibility with legacy commercial UEs and also test the performance. The commercial 5G UEs used in our tests are ZTE Axon 20 and Axon 30 with 2T4R.

Prototype	Figures	Performance
The 1 st SBFD prototype with TUE (4T4R)		Peak UL data rate: 1.4Gbps E2E latency: less than 4ms
The 2 nd SBFD prototype with commercial UE (2T4R)		Peak UL data rate: 700Mbps E2E latency: around 4ms

Note: More detailed configuration in the appendix.

Prototypes of SBFD

- A field test of the SBFD prototype with commercial UE is also carried out in ZTE Xi'an Research Institute.

Prototype	Figures	Performance
<p data-bbox="402 749 563 786">Field test</p> <p data-bbox="277 832 685 922">SBFD prototype with commercial UE (2T4R)</p>	 	<p data-bbox="1765 775 2270 818">Peak UL data rate: 672 Mbps</p> <p data-bbox="1765 858 2232 901">E2E latency: around 5.3ms</p>

Observations

- SBFD is a promising technology for 5G-A and 6G
 - UP performance gain is observed in almost all cases under different assumptions in different scenarios
 - DL performance gain or no gain/loss is observed in SBFD Alt.2 with small packet size and SBFD Alt.4 with large/small packet size, except for some high traffic load scenarios.
 - DL performance loss is observed in SBFD Alt.2 with large packet size due to less DL resource allocation for DL in SBFD.
 - SBFD prototypes verify the SBFD feasibility and performance for both TUE and commercial UEs supporting flexible symbols.

目录

CONTENTS

01

Background

02

Simulation & Prototypes of SBFD

03

Summary and Draft Objective

Summary of SBFDF framework/operation

■ Basic SBFDF framework

- Subband-based configuration/operation within one TDD carrier
- Semi-static configuration of subband time and frequency location, same subband frequency resources across different SBFDF symbols
- Both time and frequency locations of subbands for SBFDF operation are known to SBFDF aware UEs
 - Frequency domain pattern: DUD, DU, UD
 - Time domain pattern: Explicit configuration of SBFDF subband time locations within a period, symbol-level SBFDF configuration in legacy DL/flexible symbols
- Semi-static SBFDF vs dynamic SBFDF
 - Semi-static SBFDF
 - UL transmissions within UL subband are allowed in the symbol
 - UL transmissions outside UL subband are not allowed in the symbol
 - DL receptions within DL subband(s) are allowed in the symbol
 - DL receptions outside DL subband(s) are not allowed in the symbol
 - FFS: Dynamic SBFDF

Summary of SBFDD framework/operation

■ Detailed SBFDD operation

- Unaligned boundaries between resource block group(s)/reporting subband(s) and SBFDD subbands
 - RBG, PRG, CSI-RS resource/report, CCE
- Resource configuration/allocation across DL subbands
 - CSI-RS resource, UE-UE CLI measurement resource
 - Wideband precoder
- Collision handling
 - Type A: Collision between UL transmissions and DL receptions in the same SBFDD symbol
 - SBFDD operation under SSB symbols
 - Type B: Collision between transmissions/receptions with transmission direction of subbands
- UL/DL transmission occasion across SBFDD symbols and non-SBFDD symbols in the same slot
- UL/DL transmissions across SBFDD symbols and non-SBFDD symbols in different slots
 - CSI-RS, SRS, PUCCH, PUSCH, PDSCH, PDCCH
- Potential RACH enhancement for SBFDD operation

Summary of CLI schemes for SBFD & dynamic TDD

■ gNB self-interference

- Guard band
- How to handle misalignment at gNB between UL receptions and DL transmissions due to configuration of non-zero $N_{TA, offset}$ at UE

■ gNB-gNB CLI handling

- SSB/CSI-RS based measurement/report, finer granularity of measurement/report
- Spatial domain coordination: beam nulling, report of high/low interfering Tx beam
- How to handle misalignment between UL timing at victim gNB and DL reception timing at victim gNB of CLI measurement resource transmitted from one or more aggressor gNB
- Coordinated scheduling: Time-domain coordination / frequency-domain coordination
 - UL muting: Transparent method vs non-transparent method
 - DL blanking
- Information exchange between gNBs

Summary of CLI schemes for SBF & dynamic TDD

■ UE-UE CLI handling

➤ L1/L2 based measurement/report

- Measurement/report metrics: RSSI, RSRP, SINR
- Method
 - Method#1: victim UE measures RSSI within DL subband
 - Method#2: victim UE measures RSRP of aggressor UE within UL subband
 - Method#3: victim UE measures RSSI within UL subband
 - Method#4 (for SINR): UE measures the signal strength of a DL signal transmitted within a DL subband and interference based on CLI measurement resources within the same DL subband
- Finer granularity of measurement/report

➤ Power control mechanism: Separate parameters for slots with CLI and slots without CLI

➤ How to handle misalignment between DL reception timing at victim UE of DL channel/signal transmitted from serving gNB and DL reception timing at victim UE of CLI measurement resource transmitted from aggressor UE(s)

➤ Spatial domain coordination

➤ Coordinated scheduling

➤ Information exchange between gNBs

Potential WI Objectives

- SBFD operation at gNB side
 - Subband-based configuration/operation within one TDD carrier
 - Semi-static configuration of subband time and frequency location, same subband frequency resources across different SBFD symbols
 - Both time and frequency locations of subbands for SBFD operation are known to SBFD aware UEs
 - Frequency domain pattern: DUD, DU, UD
 - Time domain pattern: Explicit configuration of SBFD subband time locations within a period, symbol-level SBFD configuration in legacy DL/flexible symbols
 - Support semi-static SBFD. Study, if agreed, support dynamic SBFD

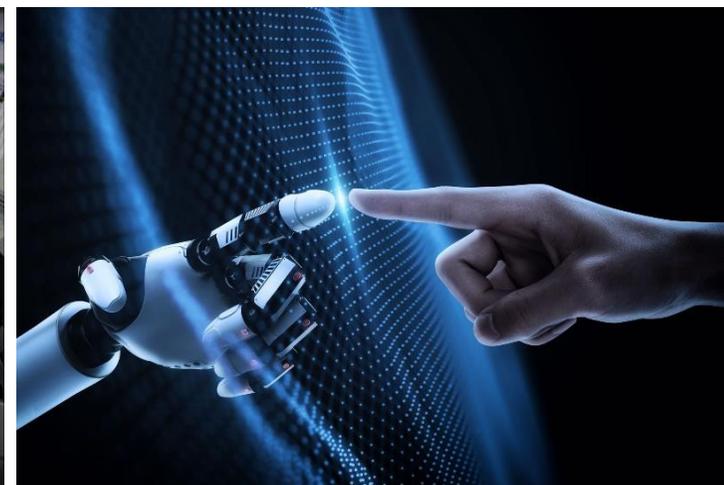
- Detailed SBFD operation
 - Unaligned boundaries between resource block group(s)/reporting subband(s) and SBFD subbands
 - RBG, PRG, CSI-RS resource/report, CCE
 - Resource configuration/allocation across DL subbands:
 - Collision handling including SBFD operation under SSB symbols
 - Type A: Collision between UL transmissions and DL receptions in the same SBFD symbol
 - Type B: Collision between transmissions/receptions with transmission direction of subbands
 - UL/DL transmission occasion across SBFD symbols and non-SBFD symbols in the same slot
 - UL/DL transmissions across SBFD symbols and non-SBFD symbols in different slots
 - Potential RACH enhancement for SBFD operation

Potential WI Objectives

■ CLI schemes for SBFD & dynamic TDD

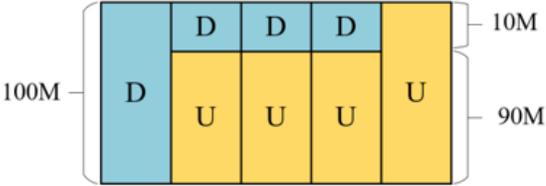
- gNB self-interference
 - Guard band
 - Misalignment at gNB between UL receptions and DL transmissions due to non-zero $N_{TA,offset}$ at UE
- gNB-gNB CLI handling
 - SSB/CSI-RS based measurement/report, finer granularity of measurement/report
 - Spatial domain coordination: beam nulling, report of high/low interfering Tx beam
 - How to handle misalignment between UL timing at victim gNB and DL reception timing at victim gNB of CLI measurement resource transmitted from one or more aggressor gNB
- UE-UE CLI handling
 - L1/L2 based measurement/report
 - Measurement/report metrics: RSSI, RSRP, SINR
 - Method: RSSI/SINR within DL subband, RSRP within UL subband, RSSI within UL subband
 - Finer granularity of measurement/report
 - Power control mechanism
 - How to handle misalignment between DL reception timing at victim UE of DL channel/signal transmitted from serving gNB and DL reception timing at victim UE of CLI measurement resource transmitted from aggressor UE(s)
- Information exchange between gNBs

Thank You



Appendix: Prototypes of SBFD

- The subband configuration and other the detailed setting about this SBFD prototype
 - The first slot and last slot are DL only slot and UL only slot with 100MHz transmission bandwidth, respectively. The DL subband is set as 10MHz and the UL subband is set as 90MHz.
 - More detailed configuration of SBFD prototypes and results can be found in our RAN1 tdoc R1-2304595

Item	Setting
Frequency	4.9GHz
BS antenna configuration	4T4R
UE antenna configuration	4T4R
BS Power	4*250mw, 30dBm in total
SBFD configuration	DXXXU non-SBFD slot: 100MHz DL subband: 10MHz UL subband: 90MHz 
Antenna isolation	21.5cm
Self-interference capability	more than 130dB

Appendix: Detailed simulation assumptions

Parameters		Value	
Scenario		Indoor office	Dense Urban Macro layer
Layout		Indoor office size 120x50 m Single layer: 12BSs per 120m x 50m	Macro layer: Hex. Grid As a layout of macro cell, 7 macro sites, 3 sectors per site model with wrap around
Numerology		14 OFDM symbol slot	
Inter-BS distance		20m	20m
Carrier frequency		4GHz	
Simulation bandwidth		100 MHz	
BS Tx power		24 dBm per 100MHz	44dBm per 100MHz
UE Tx power		23dBm	
Frame structure		Legacy TDD DDDSU, S={12D:2G:0U] SBFD: XXXXU and XXXXX S = {(subband-1:D; subband-2:U; subband-3:D) , 273RBs, 104:55:104(DUD),- Guard RB: 5RBs in each side 1symbol gap between S and U symbol.	
TxRU mapping		Per panel, reuse models in TR 36.897. Option 1: a single TxRU is mapped per panel per polarization.	
BS antenna configuration		Legacy TDD: <ul style="list-style-type: none"> ■ = (4,4,2,1,1; 4,4) ■ = (0,5,0,5)λ, +45°/-45° polarization; SBFD: <ul style="list-style-type: none"> ■ SBFD antenna configuration option-2 (Method2- 1) ■ Two panel groups ■ For each panel group: = (4,4,2,1,1). ■ Number of TxRUs: same as legacy TDD ■ = (0,5, 0,5)λ, +45°/-45° polarization, (d_u,d_v) = (0, 4)λ 	Legacy TDD: <ul style="list-style-type: none"> ■ = (8,8,2,1,1;2,8) ■ = (0,5, 0,8)λ, +45°/-45° polarization; SBFD: <ul style="list-style-type: none"> ■ SBFD antenna configuration option-2 (Method2- 1) ■ Two panel groups ■ For each panel group: = (8,8,2,1,1). ■ Number of TxRUs: same as legacy TDD ■ = (0,5, 0,8)λ, +45°/-45° polarization, (d_u,d_v) = (0, 4)λ
BS antenna height		3m	25m
BS antenna radiation pattern		Reuse Table 10 in Report ITU-R M.2412 for both FR1&FR2-1 (same as Wall-mount model in Table A.2.1-7 in TR 38.802)	Reuse Table 9 in Report ITU-R M.2412 (same as 3-sector BS antenna radiation model in Table A.2.1-6 in TR 38.802)
BS receiver noise figure		5dB for 4GHz	
UE antenna configuration		For 4GHz: 2 Tx/4 Rx antenna ports 2Tx: (M,N,P,Mg,Ng;Mp,Np) = (1,1,2,1,1;1,1), (dH,dV) = (N/A, N/A) λ , 0°, 90° polarization 4Rx: (M,N,P,Mg,Ng;Mp,Np) = (1,2,2,1,1;1,2), (dH,dV) = (0,5, N/A) λ , 0°, 90° polarization	
UE antenna radiation pattern		Omni-directional with 0 dBi element gain	
UE receiver noise figure		9 dB for 4GHz	
UE power control		P0= -60; alpha =0.6	P0 = -86, alpha =0.8
Minimum BS-UE (2D) distance		0m	35m
Minimum UE-UE (2D) distance		1m	
UE cluster number per macro cell (X)		-	2
UE outdoor/indoor proportion		100% indoor in houses: 3km/h	20% outdoor in cars: 30km/h; 80% indoor in houses: 3km/h
Indoor UE height		1.5m	1.5m
Radius of cluster (R)		-	20m
Minimum distance between macro TRP to UE cluster center		-	55m
Minimum distance between two UE cluster centers		-	-
UE density		10 UEs per TRxP	20 UEs per TRxP
UE receiver		MMSE-IRC	
Feedback assumption		Realistic	
Channel estimation		Ideal	
UE processing capability		UE processing capability 2	
UE attachment		Based on RSRP from port 0	
Polarized antenna model		Model-1 in clause 7.3.2 in TR 38.901	
DL/UL Modulation		Up to 64QAM	
Handover margin		3 dB	
Transmission scheme and Scheduling		SU-MIMO with PF	
gNB-gNB co-channel inter-subband	Co-site inter-sector	The same assumption as self-interference suppression.	
	Inter-site	TX leakage: gNB ACLR = 45dB Receiver impairment: gNB ACS=46dB Tx and Rx isolation: path loss between the aggressor gNB and victim gNB	
UE-UE co-channel inter-subband		IRE model is applied TX leakage: UE ACLR = 50dB Receiver impairment: UE ACS= 33dB	