Final Performance Evaluation of 3GPP NR Air Interface for eMBB

Volker Pauli, Christiane Dietrich, Lang Yu, Baran Elmali, Eiko Seidel
Nomor Research GmbH, Munich, Germany
March 2020

1. Introduction

Different air interfaces developed by various groups around the world claim to meet the 5G performance targets as defined in the International Mobile Telecommunications 2020 (IMT-2020) requirements in the report ITU-R M.2410-0 [3]. 5G networks are already being rolled out, but do those networks really fulfill the requirements of the ITU-R?
3GPP submitted the NR radio interface technology (RIT) as proposed 5G RIT candidate and in combination with the enhanced LTE as set of RIT, a so called SRIT, to the ITU-R [1][2]. The assessment of the proponent submission and self-evaluation has been made by different evaluation groups in the ITU-R by analytical, inspection and simulation methods as specified M.2412-0 [4].
From the European side such evaluation is being performed by 5G Infrastructure Association (5G-IA) within the scope or the 5G Infrastructure Public Private Partnership (5G-PPP). Details about evaluation group, 5G-PPP's IMT-2020 standardization and evaluation process can be found on the 5G-PPP homepage [5]. Nomor Research contributed the system level simulation results to the evaluation group of the 5G-PPP consortium as an independent source. The evaluation has been submitted to 34th meeting of the ITU-R Working Party 5D [6]. Simulation results of Nomor Research in this report are labeled as "Source 1".
In the following, a summary of our simulation-based evaluation using the 5G NR system simulator RealNeS is being provided. General information on the simulation approach and the initial calibration of the 5G NR system level simulator RealNeS is provided in a related White Paper published in 2018 [7].

2. Simulation Scenarios

The evaluation was performed for eMBB traffic for all specified environment such as Indoor Hotspot, Dense Urban and Rural eMBB with various configurations. The scenarios are different with respect to the Base Station (BS) and User Equipment (UE) drop model, the inter-site distance, antenna height, user distribution (indoor versus outdoor UEs) and UE speed as shown in Table 1.

Table 1: User experienced data rate for Dense Urban eMBB configuration B

	Indoor Hotspot eMBB	Dense Urban eMBB	Rural eMBB
Antenna height	3 m	25 m	35 m
Inter-site distance	20 m	200 m	1732 m
Device deployment	100% indoor	80% indoor 20% outdoor	50% indoor 50% outdoor
UE speed	3 km/h	Indoor 3 km/h Outdoor car 30 km/h	Indoor 3 km/h Outdoor car 120 km/h
Min. distance BS-UE	0 m	10 m	10 m

The Indoor test environment corresponds to an office floor where 12 sites are placed every 20 m at a height of 3 m. All user are indoor users and walk around the office building.

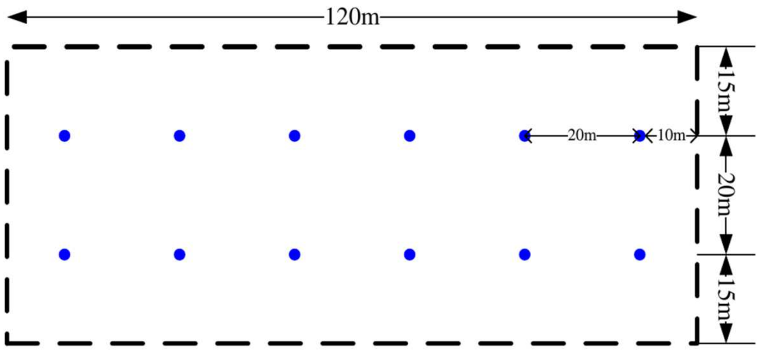

Figure 1: Layout Indoor Hotspot scenario [4]

The dense urban and rural test environments follow a homogenous hexagonal layout with inter-site distances of 200 m for Dense Urban and 1732 m for rural. While in Dense Urban most of the users are indoor, only half of the users are indoor in the rural scenarios. The remaining users are in cars and move within the simulation area with a speed of 30 km/h and 120 km/h, respectively.

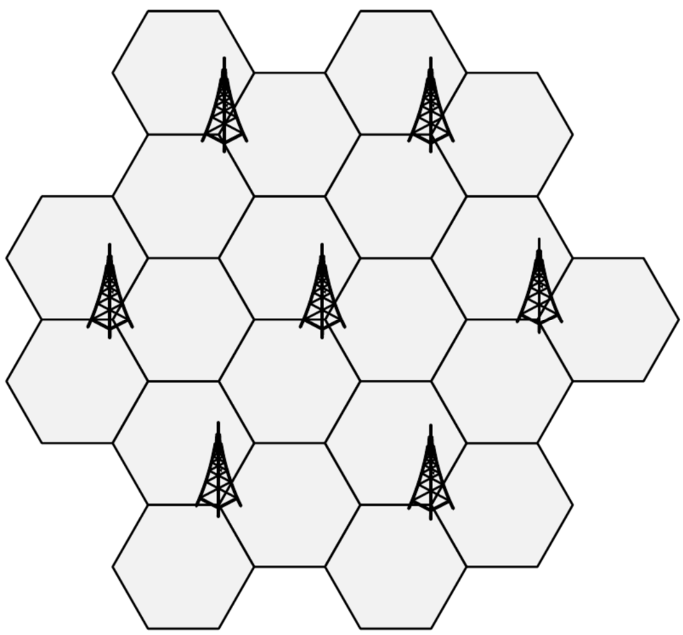

Figure 2: Layout Dense Urban and Rural scenarios [4]

While in the Indoor Hotspot scenarios the inter-cell interference is limited to the sites in the office building, other rings of base stations surround the Dense Urban and Rural scenarios.

Within a simulation scenario different configuration sets for different frequency bands are being simulated. A summary of the scenario configurations is provided in Annex A. Configurations included single and multi-band configurations including supplementary uplink, FDD and TDD duplexing schemes with different frame structure configuration. Of course, different antenna configurations of the different frequency bands have strong impact on the applicable MIMO techniques affecting the overall performance significantly.

In the following sections system-level simulations results for the following Key Performance Indicators are provided:

- 5%ile user spectral efficiency
- average cell spectral efficiency
- user experienced data rate
- area traffic capacity.

3. Simulation Results

3.1 User Experience Data Rate in Dense Urban Environments

The ITU-R minimum requirements on 5th percentile user spectral efficiency is given in [3]. User experienced data rate is the 5% point of the cumulative distribution function (CDF) of the user throughput. User throughput (during active time) is defined as the number of correctly received bits, i.e. the number of bits contained in the service data units (SDUs) delivered to Layer 3, over a certain period of time. The user data rate can be calculated by multiplying the aggregated bandwidth with the spectral efficiency of the user.

Configuration A (Carrier Frequency = 4 GHz)
A subcarrier spacing of 15 KHz is used for up- and downlink. In the downlink a massive MIMO configuration is used applying Multi-User MIMO. In the uplink where only 4 transmit antennas with limited power are available a Single-User MIMO scheme is applied.

Table 2: User experienced data rate for Dense Urban eMBB configuration A

	TX-RU Config.	Sub-Carrier Spacing	ITU require-ment [Mbit/s]	FDD [Mbit/s]	TDD [Mbit/s]
Downlink	32T4R MU-MIMO	15 KHz	100	103.37 @400 MHz	104.60 @600 MHz
Uplink	4T32R SU-MIMO	15 KHz	50	51.00 @680 MHz	52.29 @800 MHz

Intra-band carrier aggregation is used with a component carrier size of 100 MHz for downlink and 40 MHz for uplink. A certain transmission bandwidth will be required to achieve the required data rate as indicated in the table. The applied TDD frame structure is "DSUUD".

Configuration B (Carrier Frequency = 30 GHz)
Different antenna and subcarrier spacing configurations are used for the mm-wave spectrum at 30 GHz. 60 KHz subcarrier spacing is the smallest subcarrier spacing in Frequency Range 2. Simulations have been performed for TDD, as FDD is usually not applied in this frequency range. The table shows that neither the uplink nor the downlink ITU-R requirements can be met in Configuration B. The reason is that the 5th percentile user requirement cannot be fulfilled due to the insufficient outdoor-to-indoor link budget. The

indoor UEs can, due to the large pathloss and penetration loss caused by the building, not be served by the outdoor base station when using such high frequency.

Table 3: User experienced data rate for Dense Urban eMBB configuration B

	TX-RU Config.	Sub-Carrier Spacing	ITU requirement [Mbit/s]	TDD [Mbit/s]
Downlink	256T8R SU-MIMO	60 KHz	100	**2.00 @3200 MHz**
Uplink	8T32R SU-MIMO	60 KHz	50	**2.13 @3200 MHz**

For the CDF of geometry received during the calibration process [7] it can be seen that there are geometry values down to – 30 dB. While the requirement cannot be fulfilled for this specific frequency band, the scenarios can be fulfilled using the configuration A at 4GHz. According to the ITU-R requirements at least one configuration must fulfill the requirements.

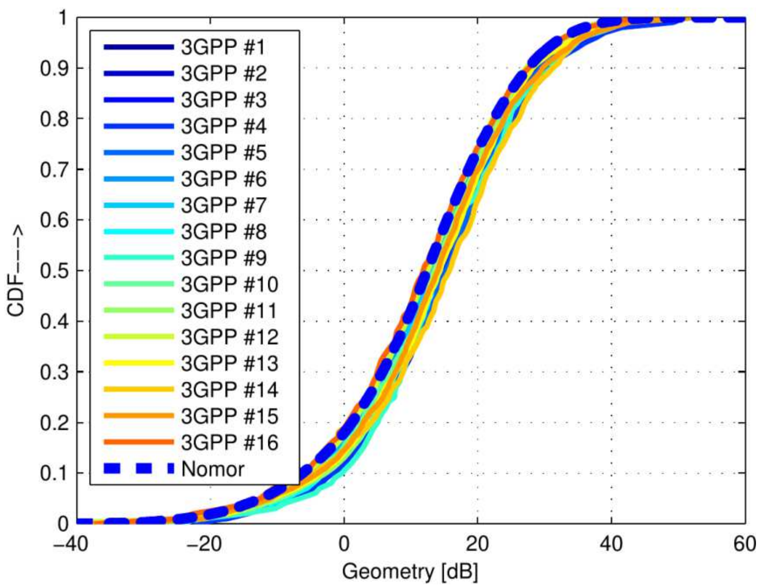

Figure 3: Distribution of WB-SINR for Urban Config B [7]

<u>Configuration C (Multi-band 4 GHz and 30 GHz)</u>
The multi-band configuration uses a 30 GHz TDD band as well as a supplementary uplink (SUL) band at 4 GHz. The same antenna and subcarrier spacing configurations as before are used. Single-User MIMO is used in uplink. The selected component carrier size was 20 MHz for the SUL band and 80 MHz for the TDD band resulting in an overall transmission bandwidth for the required data rate as indicated in the table below.

Table 4: Uplink user experienced data rate for Dense Urban eMBB configuration C

	Carrier Frequency	Duplexing Scheme	System Bandwidth	ITU requirement [Mbit/s]	TDD [Mbit/s]
Uplink	4GHz	FDD	80 MHz (full uplink)	50	64.90
	30 GHz	TDD (DSUUD)	560 MHz (partial uplink)		

It should be noted that this is based on a homogenous cell layout with an Inter-site Distance of 200 m. The UEs that cannot be served in the mm-wave band are offloaded to the lower 4 GHz band. Approximately 50% users (e.g. indoor UEs) with lower reference signal received power on the 30 GHz band (below -106 dBm) are offloaded to 4 GHz SUL band.

Additional simulations have been performed for heterogeneous networks, where three additional micro transmission points with additional users in its proximity are randomly dropped in the existing cell layer on a per sector basis. Both network layers operate on the 4 GHz carrier frequency. In this case the downlink user experienced data rate requirement can already be fulfilled by using the 4 GHz band only.

Table 5: Downlink user experienced data rate for Dense Urban eMBB configuration C

	Carrier Frequency	Duplexing Scheme	System Bandwidth	ITU requirement [Mbit/s]	TDD [Mbit/s]
Downlink	4 GHz	TDD (DSUUD)	1200 MHz	100	104.71

The KPI user experience data rate is computed based on the 5%ile of the user spectral efficiency and therefore the required system bandwidth is quite high. While such heterogeneous network configuration might not perform best for this KPI, this configuration offers a much higher area capacity as described later.

3.2 5th Percentile User Spectral Efficiency

The ITU-R minimum requirements on 5th percentile user spectral efficiency is given in [3]. The 5th percentile user spectral efficiency is the 5% point of the CDF of the normalized user throughput. The normalized user throughput is defined as the number of correctly received bits, i.e. the number of bits contained in the SDUs delivered to Layer 3, over a certain period, divided by the channel bandwidth and is measured in bit/s/Hz.

The evaluation of the 5th percentile user spectral efficiency is conducted for the three different test environments of eMBB indoor hotspot, dense urban and rural. The test environments and evaluation configuration parameters are described in [4].

Test environment	NR Duplexing Method	Downlink (bit/s/Hz/TRxP)		Uplink (bit/s/Hz/TRxP)	
		1 / 3 sectors	ITU-R	1 / 3 sectors	ITU-R
Indoor Hotspot – eMBB	NR TDD 4 GHz	0.36 / 0.34	0.3	0.49 / 0.31	0.21
	NR FDD 4 GHz	0.37 / 0.31		0.48 / 0.28	
	NR TDD 30 GHz	0.48 / 0.34		0.40 / 0.23	
	NR FDD 30 GHz	0.39 / 0.30		0.41 / 0.31	

Dense Urban – eMBB	TDD 4 GHz	0.30	0.225	0.15	0.15
	FDD 4 GHz	0.25		0.3	
	FDD 30 GHz	**0.0004**		**0.029**	
Rural – eMBB	TDD 700 MHz	0.21	0.12	0.06	0.045
	FDD 700 MHz	0.19		0.24	
	TDD 4 GHz	0.23		0.062	
	FDD 4 GHz	0.25		0.12	

For the indoor environments two different antenna configurations, a 1-sector and a 3-sector configuration, are applied. NR TDD uses the frame structure 'DSUUD'. Once again it can be observed that the required rate is fulfilled except for the Dense Urban scenario at 30 GHz where the outdoor-to-indoor transmission is not feasible.

3.3 Average Spectral Efficiency

The ITU-R minimum requirements on average spectral efficiency are given in [3]. Average spectral efficiency is the aggregate throughput of all users (the number of correctly received bits, i.e. the number of bits contained in the SDUs delivered to Layer 3, over a certain period of time) divided by the channel bandwidth of a specific band divided by the number of transmission points and is measured in bit/s/Hz/TRxP.

The evaluation of the average spectral efficiency is conducted for the three different test environments of eMBB indoor hotspot, dense urban and rural. The test environments and evaluation configuration parameters are described in [4].

Test environment	NR Duplexing Method	Downlink (bit/s/Hz/TRxP)		Uplink (bit/s/Hz/TRxP)	
		1 / 3 sectors	ITU-R	1 / 3 sectors	ITU-R
Indoor Hotspot – eMBB	NR TDD 4 GHz	13.6 / 12.9	9	15.5 / 15.3	6.75
	NR FDD 4 GHz	12.14 / 12.17		8.49 / 7.48	
	NR TDD 30 GHz	14.7 / 11.2		7.4 / 7.33	
	NR FDD 30 GHz	13.06 / 10.66		7.58 / 6.94	
Dense Urban – eMBB	TDD 4 GHz	16.90	7.8	8.4	5.4
	TDD 4 GHz	12.86		8.8	
	TDD 30 GHz	9.62		7.42	
Rural – eMBB	FDD 700 MHz	8.45	3.3	4.74	1.6
	TDD 700 MHz	6.24		4.10	
	FDD 4 GHz	16.50		7.01	
	TDD 4 GHz	14.67		6.88	

The same NR TDD frame structure 'DSUUD' is used and results are provided for 1 and 3 sectors for the indoor environment. A transmission bandwidth of 20 MHz is used at a carrier frequency of 4 GHz and 80 MHz transmission bandwidth at a carrier frequency of 30 GHz. The spectral efficiency targets of the ITU-R are well exceeded in the results, particularly due to the extensive use of Multi-User MIMO transmission.

3.4 Area Traffic Capacity for Indoor Hotspot

ITU-R defines an Area Capacity requirement of 10 Mbit/s/m^2 for a 5G indoor hotspot scenario [3]. Area traffic capacity is defined as average spectral efficiency times the aggregated bandwidth divided by the simulation area. Simulations are performed for 5G NR TDD in the Indoor Hotspot eMBB environment at carrier frequency

4 GHz for configuration A and 30 GHz for Configuration B. Once again, both 1 and 3-sector configuration have been simulated.

Table 6: Area traffic capacity for indoor hotspot eMBB configuration A

	TX-RU Config.	Sub-Carrier Spacing	ITU requirem. [Mbit/s/m2]	FDD [Mbit/s]	TDD [Mbit/s]
1 sector per site	32T4R MU-MIMO	15 KHz	10	11.77 @400 MHz	10.60 @600 MHz
3 sectors per site				12.04 @120 MHz	10.04 @200 MHz

Table 7: Area traffic capacity for indoor hotspot eMBB configuration B

	TX-RU Config.	Sub-Carrier Spacing	ITU requirem. [Mbit/s/m2]	FDD [Mbit/s]	TDD [Mbit/s]
1 sector per site	32T4R MU-MIMO	60 KHz	10	12.63 @400 MHz	11.41 @600 MHz
3 sectors per site				15.17 @200 MHz	17.43 @400 MHz

It can be observed that NR TDD and FDD meet the ITU-R requirement in terms of area traffic capacity in both configurations.

4 Summary

Evaluation groups of the ITU-R evaluated the submitted 5G proposals for predefined key performance indicators in order to assess whether the proposals would meet the ITU-R's performance requirements for IMT-2020. From the European side such an evaluation has been performed by the 5G Infrastructure Association (5G-IA) within the scope or the 5G Infrastructure Public Private Partnership (5G-PPP). Nomor Research contributed system level simulation results to the evaluation group of the 5G-PPP consortium as an independent source.

This white paper provides a summary of our simulation-based evaluation of the 5G NR air interface as defined by 3GPP. It was shown that the requirements for the user experience data rate, the 5%ile user spectral efficiency, the average cell spectral efficiency, the user experienced data rate and the area traffic capacity can be fulfilled. In the Dense Urban environment serving indoor UEs from an outdoor BS proved to be impractical for the 30 GHz band while it is still realistic for the 4 GHz spectrum.

<u>Simulation and Consultancy Services</u>

Our standard complaint and calibrated simulators (link, system and network level) are available for research projects and simulation campaigns. Please contact us in case you are interested in our services by sending an email to info@nomor.de. Other 3GPP related consultancy services are

- Research, Analyses and Concept Development
- Demonstration and Prototyping
- 3GPP Standardisation Support
- Technology Training
- Patents Support

Acknowledgement

Our simulation work was supported by the following 5G-PPP projects

- 5G MoNArch,
- 5G Xcast,
- Global5G.org CSA and
- 5G Solutions.

We would also like to acknowledge the support of our partners in the 5G-IA's evaluation group from other 5G-PPP projects

- 5G Essence,
- One 5G,
- To-Euro-5G CSA
- 5G Genesis,
- 5G Solutions,
- 5G Tours,
- 5G VINNI,
- Clear5G,
- Full5G CSA

and industry partners

- Huawei,
- Intel,
- Nokia,
- Telenor,
- Turkcell and
- ZTE Wistron Telecom AB.

References

[1] ITU-R WP5D: Acknowledgement of Candidate SRIT Submission from 3GPP Proponent under Step 3 of the IMT-2020 Process. Document IMT-2020/13-E, 23 July 2019.

[2] ITU-R WP5D: Acknowledgement of Candidate RIT Submission from 3GPP Proponent under Step 3 of the IMT-2020 Process. Document IMT-2020/14-E, 23 July 2019.

[3] ITU-R: Minimum requirements related to technical performance for IMT-2020 radio interface(s). Report ITU-R M.2410-0, (11/2017).

[4] ITU-R: Guidelines for evaluation of radio interface technologies for IMT-2020. Report ITU-R M.2412-0, (10/2017).

[5] https://5g-ppp.eu/5g-ppp-imt-2020-evaluation-group/

[6] "Evaluation Report From the 5G Infrastructure Association on IMT-2020 Proposals IMT-2020/14, 15, 16, Parts of 17" 34th meeting of Working Party 5D, Geneva, Switzerland, 19 – 26 February 2020 https://5g-ppp.eu/wp-content/uploads/2020/02/5G-IA-Final-Evaluation-Report-3GPP-1.pdf

[7] L. Yu, C. Dietrich, V. Pauli, "IMT- 2020 Evaluation: Calibration of NOMOR's System Simulator", Nomor White Paper, November 2018. http://nomor.de/2018/imt-2020-evaluation-calibration-of-nomors-system-simulator/

Annex A: Detailed simulation parameters for system-level simulation

In this Annex the parameters are summarized, which are used in the system-level simulations performed to evaluate

- 5%ile user spectral efficiency
- average cell spectral efficiency
- user experienced data rate
- area traffic capacity.

Simulations Assumptions for TDD: DSUUD and NR FDD

Parameters	Values		
Test environment	**Indoor Hotspot – eMBB**	**Dense Urban – eMBB**	**Rural - eMBB**
Evaluation configuration	Configuration A/B	Configuration A/B	Configuration A/B/C
Channel model	InH_B	UMa_B	RMa_B
ISD	20 m	200 m	Configuration A/B: 1732 m Configuration C: 6000 m
TDD frame structure	DSUUD	DSUUD	DSUUD
Carrier frequency	Configuration A: 4 GHz Configuration B: 30 GHz	Configuration A: 4 GHz Configuration B: 30 GHz	Configuration A: 700 MHz Configuration B: 4 GHz Configuration C: 700 MHz
System bandwidth	TDD: Configuration A: 20 MHz Configuration B: 80 MHz	TDD: 20 MHz	TDD: 20 MHz
	FDD: 10 MHz	FDD: Configuration A: 10 MHz Configuration B: 40 MHz	FDD: 10 MHz
Subcarrier spacing	Configuration A: 15 kHz Configuration B: 60 kHz	Configuration A: 15 kHz Configuration B: 60 kHz	15 kHz
Number of symbols per slot	14	14	14
Number of antenna elements per TRxP	Configuration A/B: 16Tx cross-polarized antennas (M,N,P,Mg,Ng;Mp,Np) = (4,4,2,1,1;4,4);	Configuration A: 64Tx cross-polarized antennas (M,N,P,Mg,Ng;Mp,Np) = (8,8,2,1,1;2,8) Configuration B: 128Tx cross-polarized antennas (M,N,P,Mg,Ng;Mp,Np) = (8,16,2,1,1;1,16)	Configuration A/C: 32Tx cross-polarized antennas (M,N,P,Mg,Ng;Mp,Np) = (8,4,2,1,1;1,4); Configuration B: 64Tx cross-polarized antennas (M,N,P,Mg,Ng;Mp,Np) = (8,8,2,1,1;2,8)

Number of TXRU per TRxP	Configuration A/B: 32TXRU: Vertical 1-to-1	Configuration A: 32TXRU: Vertical 2-by-8 Configuration B: 32TXRU: Vertical 1-by-16	Configuration A/C: 8TXRU, Vertical 1-by-8; Configuration B: 32TXRU, Vertical 2-by-8
Number of antenna elements per UE	Configuration A: 4Rx with 0°and 90° polarization Configuration B: 32Rx with 0° and 90° polarization (M,N,P,Mg,Ng; Mp,Np) = (2,4,2,1,2; 1,2)	Configuration A: 4Rx with 0°and 90° polarization Configuration B: 32Rx with 0° and 90° polarization (M,N,P,Mg,Ng; Mp,Np) = (2,4,2,1,2; 1,2)	Configuration A: 2Rx Configuration B/C: 4Rx with 0°and 90° polarization
Transmit power per TRxP	TDD: Configuration A: 24 dBm; Configuration B: 23 dBm	TDD: 44 dBm	TDD: 46 dBm
	FDD: 21 dBm	FDD: 41 dBm	FDD: 46 dBm
TRxP number per site	1 or 3	3	3
Mechanic tilt	1 TRxP / site: 180° in GCS (pointing to the ground) 3 TRxP / site: 110° in GCS	90° in GCS (pointing to the horizontal direction)	90° in GCS (pointing to the horizontal direction)
Electronic tilt	Configuration A: 90° in LCS Configuration B: According to Zenith angle in "Beam set at TRxP"	105° in LCS	Configuration A/B: 100° in LCS Configuration C: 92° in LCS
Beam set at TRxP	Configuration B: Azimuth angle φi = [0], Zenith angle θj = [pi/2]	N/A	N/A
Beam set at UE	Configuration B: Azimuth angle φi = [-pi/4, pi/4]; Zenith angle θj = [pi/4, 3*pi/4]	Configuration B: Azimuth angle φi = [-pi/4, pi/4]; Zenith angle θj = [pi/4, 3*pi/4]	N/A
UT attachment	Based on RSRP (Eq. (8.1-1) in TR 36.873) from port 0	Based on RSRP (Eq. (8.1-1) in TR 36.873) from port 0	Based on RSRP (Eq. (8.1-1) in TR 36.873) from port 0
Scheduling	MU-PF	MU-PF	MU-PF
Downlink MIMO mode	MU-MIMO with rank 1-2 adaptation per user;	MU-MIMO with rank 1-2 adaptation per user;	MU-MIMO with rank 1-2 adaptation per user;

		Configuration A: Maximum MU layer = 12; Configuration B: Maximum MU layer = 6	Maximum MU layer = 12	Maximum MU layer = 8 for 8Tx and maximum MU layer = 12 for 32Tx;
Guard band ratio		TDD: Configuration A: 8.2 % for 30 kHz SCS and 4.6 % for 15 kHz SCS (for 20 MHz); Configuration B: 5.5 % (for 80 MHz);	TDD: 8.2 % for 30 kHz SCS and 4.6 % for 15 kHz SCS (for 20 MHz)	8.2 % for 30 kHz SCS and 4.6 % for 15 kHz SCS (for 20 MHz)
		FDD: 6.4 % (for 10 MHz)	FDD: 6.4 % (for 10 MHz)	FDD: 6.4 % (for 10 MHz)
BS receiver type		MMSE-IRC	MMSE-IRC	MMSE-IRC
CSI feedback		5 slots period based on non-precoded CSI-RS with delay	For 32Tx: 5 slots period based on non-precoded CSI-RS with delay;	5 slots period based on non-precoded CSI-RS with delay
SRS transmission		Precoded SRS for 2Tx ports; Period: 5 slots; 2 symbols	Precoded SRS for 2Tx ports; Period: 5 slots; 2 symbols	Precoded SRS for 2Tx ports; Period: 5 slots; 2 symbols
Downlink precoder derivation		TDD: SRS based	TDD: SRS based	TDD: SRS based
		FDD: NR Type II codebook (4 beams, WB+SB quantization, 8 PSK)	FDD: NR Type II codebook (4 beams, WB+SB quantization, 8 PSK)	FDD: NR Type II codebook (4 beams, WB+SB quantization, 8 PSK)
Downlink Overhead	PDCCH	2 complete symbols	2 complete symbols	2 complete symbols
	DMRS	Type II, based on MU-layer (dynamic in simulation)	Type II, based on MU-layer (dynamic in simulation)	Type II, based on MU-layer (dynamic in simulation)
	CSI-RS	FDD: 32 ports per 5 slots	FDD: 32 ports per 5 slots	FDD: 8/16/32 ports for 8Tx/16Tx/32Tx
		TDD: 32 ports per 5 slots	TDD: For 64Tx, 4 ports per UE per 5 slots; For 32Tx, 32 ports per 5 slots	TDD: 8/16/32 ports for 8Tx/16Tx/32Tx
	CSI-RS for IM	ZP CSI-RS with 5 slots period; 4 RE/PRB/5 slots	ZP CSI-RS with 5 slots period; 4 RE/PRB/5 slots	ZP CSI-RS with 5 slots period; 4 RE/PRB/5 slots
	SSB	1 SSB per 10 ms	1 SSB per 10 ms	1 SSB per 10 ms
	TRS	2 consecutive slots per 20ms, 1 port, maximal 52 PRBs	2 consecutive slots per 20ms, 1 port, maximal 52 PRBs	2 consecutive slots per 20ms, 1 port, maximal 52 PRBs

	PTRS	Configuration B: 2 ports PT-RS, (L,K) = (1,4) L is time domain density and K is frequency domain density	N/A	N/A
Channel estimation		Non-ideal	Non-ideal	Non-ideal
Waveform		OFDM	OFDM	OFDM
UE power class		23 dBm	23 dBm	23 dBm
Uplink scheduling		SU-PF	SU-PF	SU-PF
Uplink MIMO mode		Configuration A: SU-MIMO with rank 2 adaptation; Configuration B: SU-MIMO with rank 4 adaptation	SU-MIMO with rank 2 adaptation	SU-MIMO with rank 2 adaptation for 2Tx/4Tx
UE precoder scheme		Codebook based	Codebook based	Codebook based
Uplink power control		$\alpha = 0.9$， $P_0 = -86$ dBm	$\alpha = 0.6$， $P_0 = -60$ dBm	Configuration A: $\alpha = 0.8$， $P_0 = -76$ dBm; Configuration B: $\alpha = 0.6$， $P_0 = -60$ dBm; Configuration C: $\alpha = 0.8$， $P_0 = -76$ dBm (FDD), $P_0 = -82$ dBm (TDD)
Power backoff model		Continuous RB allocation: follow TS 38.101 in Section 6.2.2; Non-continuous RB allocation: additional 2 dB reduction	Continuous RB allocation: follow TS 38.101 in Section 6.2.2; Non-continuous RB allocation: additional 2 dB reduction	Continuous RB allocation: follow TS 38.101 in Section 6.2.2; Non-continuous RB allocation: additional 2 dB reduction
Uplink Overhead	PUCCH	FDD: for each 10 slots, 2 slots with 3 PRB and 14 OS, 8 slots with 1 PRB and 2 OS; TDD: for each 10 slots, 2 slots with 3 PRB and 14 OS	FDD: for each 10 slots, 2 slots with 3 PRB and 14 OS, 8 slots with 1 PRB and 2 OS; TDD: for each 10 slots, 2 slots with 3 PRB and 14 OS	FDD: for each 10 slots, 2 slots with 3 PRB and 14 OS, 8 slots with 1 PRB and 2 OS; TDD: for each 10 slots, 2 slots with 3 PRB and 14 OS
	DMRS	Type II, 2 symbols (including one additional DMRS symbol), multiplexing with PUSCH	Type II, 2 symbols (including one additional DMRS symbol), multiplexing with PUSCH	Type II, 2 symbols (including one additional DMRS symbol), multiplexing with PUSCH

	SRS	2 symbols per 5 slots,	2 symbols per 5 slots,	2 symbols per 5 slots,
	PTRS	Configuration B: 2 ports PT-RS, (L,K) = (1,4) L is time domain density and K is frequency domain density	N/A	N/A