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TECHNOLOGY ASPECTS

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FINAL EVALUATION REPORT FROM THE 5G INFRASTRUCTURE ASSOCIATION ON IMT-2020 PROPOSALS IMT-2020/ 14, 15, 16, PARTS OF 17

This contribution contains in Attachment 1 the Final Evaluation Report from the Independent Evaluation Group 5G Infrastructure Association (<http://www.itu.int/oth/R0A0600006E/en>). The report contains a detailed analysis of the analytical, inspection and simulation characteristics defined in ITU-R Reports M.2410-0, M.2411-0 and M.2412-0 [1] – [3] using a methodology described in Report ITU-R M.2412-0 [3].

The final report contains analytical, simulation and inspection evaluation results. This report includes updates to the preliminary report, which was submitted to the 33rd meeting on Working Party 5D.

The evaluation targets the SRIT proposal contained in IMT-2020/13-E [4] (3GPP SRIT) and IMT-2020/14-E [5] (3GPP RIT), as well as the technically very similar proposals in IMT-2020/15-E [6] (People's Republic of China), IMT-2020/16-E [7] (Republic of Korea) and IMT-2020/17-E [8] (ETSI TC DECT and DECT Forum "3GPP 5G NR" component RIT).

The attached evaluation report consists of 3 Parts:

- Part I: Administrative Aspects of 5G Infrastructure Association
- Part II: Technical Aspects of the work in 5G Infrastructure Association
- Part III: Conclusion

The report is structured according to the proposed structure in [9].

¹ Submitted on behalf of the Independent Evaluation Group 5G Infrastructure Association.

² This contribution is based on work underway within the research in 5G PPP and 5G Infrastructure Association, see <https://5g-ppp.eu/>. The views expressed in this contribution do not necessarily represent the 5G PPP.

ATTACHMENT 1

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PART I

Administrative aspects of 5G Infrastructure Association

I.1 Name of the Independent Evaluation Group

The Independent Evaluation Group is called *5G Infrastructure Association*.

I.2 Introduction and background of 5G Infrastructure Association

The 5G Infrastructure Association Independent Evaluation Group was launched by the 5G Infrastructure Association as part of 5G Public Private Partnership (5G PPP) in October 2016 by registration at ITU-R.

The 5G Public Private Partnership (5G PPP) is a sub-research program in Horizon 2020 of the European Commission. 5G Infrastructure Association is representing the private side in 5G PPP and the EU Commission the public side. The Association was founded end of 2013. The Contractual Arrangement on 5G PPP was signed by the EU Commission and representatives of 5G Infrastructure Association in December 2013. 5G PPP is structured in three program phases.

- In Phase 1 from July 1, 2015 to 2017 19 projects researched the basic concepts of 5G systems in all relevant areas and contributed to international standardization (<https://5g-ppp.eu/5g-ppp-phase-1-projects/>).
- Phase 2 started on June 1, 2017 with 23 projects (<https://5g-ppp.eu/5g-ppp-phase-2-projects/>). The focus of Phase 2 is on the optimization of the system and the preparation of trials.
- The Phase 3 is implemented with 14 projects (<https://5g-ppp.eu/5g-ppp-phase-3-projects/>)
 - Part 1: 3 Infrastructure Projects,
 - Part 2: 3 Automotive Projects and
 - Part 3: 8 Advanced 5G validation trials across multiple vertical industries. This phase is addressing the development of trial platforms especially with vertical industries, large scale trials, cooperative, connected and automated mobility, 5G long term evolution as well as international cooperation.

In each phase around 200 organizations are cooperating in the established projects.

The main key challenges of the 5G PPP Program are to deliver solutions, architectures, technologies and standards for the ubiquitous 5G communication infrastructures of the next decade:

- Providing 1000 times higher wireless area capacity and more varied service capabilities compared to 2010.
- Saving up to 90% of energy per service provided. The main focus will be in mobile communication networks where the dominating energy consumption comes from the radio access network.
- Reducing the average service creation time cycle from 90 hours to 90 minutes.
- Creating a secure, reliable and dependable Internet with a “zero perceived” downtime for services provision.
- Facilitating very dense deployments of wireless communication links to connect over 7 trillion wireless devices serving over 7 billion people.
- Enabling advanced User controlled privacy.

The Independent Evaluation Group is currently supported by the following 5G PPP Phase 2 projects:

- 5G Essence,
- 5G MoNArch,
- 5G Xcast,
- One 5G and
- To-Euro-5G CSA

and the 5G PPP Phase 3 projects

- 5G Genesis,
- 5G Solutions,
- 5G Tours,
- 5G VINNI,

- Clear5G,
- Full5G CSA,
- Global5G.org CSA

and the 5G Infrastructure Association members

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

This Evaluation Group is evaluating all 16 evaluation characteristics according to Table 2 by means of analytical, inspection and simulation activities in order to perform a full evaluation. For simulation purposes simulators at different Evaluation Group member are used, where different evaluation characteristics are mapped to different simulators. Simulators are being calibrated where needed in order to provide comparable results. Calibration results and the calibration approach are published (c.f. Section I-6) in order to provide this information to the other Independent Evaluation Groups to support the consensus building process in ITU-R WP 5D.

I.3 Method of work

The 5G Infrastructure Association Evaluation Group is organized as Working Group in 5G PPP under the umbrella of the 5G Infrastructure Association. Evaluation activities are executed according to a commonly agreed plan and conducted work through e.g.:

- Physical meetings and frequent telephone conferences where the activities are planned and where action items are given and followed up.
- Frequent email and telephone discussions among partners on detailed issues on an ad-hoc basis.
- File sharing on the web.
- Participation in the ITU-R Correspondence Group dedicated to the IMT-2020 evaluation topics.

In addition, the Evaluation Group participated in a workshop organized by 3GPP on October 24 and 25, 2018 in Brussels and the ITU-R WP5D Evaluation Workshop on December 10 and 11, 2019 in Geneva at the 33rd meeting of Working Party 5D. In that workshop the Evaluation Group presented the work method, work plan, channel model calibration status, baseline system calibration assumptions, and available evaluation results.

At and after the ITU-R workshop the Evaluation Group communicated with other Evaluation Groups as well regarding calibration and is making material openly available.

Open issues in the system description were discussed and clarified with 3GPP.

Public information on the calibration work is available at the home page listed in Section I-6.

The assessment of the proponent submission and self-evaluation has been made by analytical, inspection and simulation methods as required in Reports ITU-R M.2410-0 [1], M.2411-0 [2] and M.2412-0 [3], see Table 2 in M.2412-0 [3] in Section I-6 for details.

I.4 Administrative contact details

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5G Infrastructure Association and 5G PPP homepage: <https://5g-ppp.eu/5g-ppp-imt-2020-evaluation-group/>.

This homepage contains public information about e.g. calibration work that the 5G Infrastructure Association has performed in order to ensure reliable simulation results as well as the Interim and Final Evaluation Report (after it will become available in February 2020).

The specific calibration results that were performed for the system- and link-level simulations used in this Evaluation Report can be found in the following documents:

- System-level calibration results:
 - White paper with description of calibration activities:
 - Matlab calibration files



Adobe Acrobat
Document



Package

- Link-level calibration results:



Adobe Acrobat
Document

I.7 Structure of this Report

This Report consists of 3 Parts:

- Part I: Administrative Aspects of 5G Infrastructure Association
- Part II: Technical Aspects of the work in 5G Infrastructure Association
- Part III: Conclusion

The report is structured according to the proposed structure in [9].

PART II

Technical aspects of the work in 5G Infrastructure Association

II.1 What candidate technologies or portions of the candidate technologies this IEG is or might anticipate evaluating?

In this report, *final* results are presented for the SRIT and RIT proposals in [4] to [8] for IMT-2020 NR and LTE components with a focus on the 3GPP submission to ITU-R by means of analytical, inspection and simulation evaluation. The complete simulation evaluations will be provided in the final evaluation report.

It should be noted that technically the proposal in [4] and [5] is nearly identical to the submission in [6] to [8] by the People's Republic of China, the Republic of Korea and the 3GPP 5G NR component RIT by ETSI TC DECT and DECT Forum. Hence, this evaluation report is valid also as an evaluation report for these proposals. Table 1 shows the evaluated proposals.

TABLE 1
Evaluated technology proposals

3GPP		China	Korea	ETSI TC DECT DECT Forum		Nufront	TSDSI
SRIT	RIT			3GPP 5G NR RIT	DECT2020		
✓	✓	✓	✓	✓	-	-	-

Table 2 is summarizing the different evaluation characteristics.

TABLE 2
Summary of evaluation methodologies

Characteristic for evaluation	High-level assessment method	Evaluation methodology in this Report	Related section of Reports ITU-R M.2410-0 and ITU-R M.2411-0
Peak data rate	Analytical	§ 7.2.2	Report ITU-R M.2410-0, § 4.1
Peak spectral efficiency	Analytical	§ 7.2.1	Report ITU-R M.2410-0, § 4.2
User experienced data rate	Analytical for single band and single layer; Simulation for multi-layer	§ 7.2.3	Report ITU-R M.2410-0, § 4.3
5 th percentile user spectral efficiency	Simulation	§ 7.1.2	Report ITU-R M.2410-0, § 4.4
Average spectral efficiency	Simulation	§ 7.1.1	Report ITU-R M.2410-0, § 4.5
Area traffic capacity	Analytical	§ 7.2.4	Report ITU-R M.2410-0, § 4.6
User plane latency	Analytical	§ 7.2.6	Report ITU-R M.2410-0, § 4.7.1
Control plane latency	Analytical	§ 7.2.5	Report ITU-R M.2410-0, § 4.7.2

Connection density	Simulation	§ 7.1.3	Report ITU-R M.2410-0, § 4.8
Energy efficiency	Inspection	§ 7.3.2	Report ITU-R M.2410-0, § 4.9
Reliability	Simulation	§ 7.1.5	Report ITU-R M.2410-0, § 4.10
Mobility	Simulation	§ 7.1.4	Report ITU-R M.2410-0, § 4.11
Mobility interruption time	Analytical	§ 7.2.7	Report ITU-R M.2410-0, § 4.12
Bandwidth	Inspection	§ 7.3.1	Report ITU-R M.2410-0, § 4.13
Support of wide range of services	Inspection	§ 7.3.3	Report ITU-R M.2411-0, § 3.1
Supported spectrum band(s)/range(s)	Inspection	§ 7.3.4	Report ITU-R M.2411-0, § 3.2

In addition, evaluations of link budgets will be provided in the final evaluation Report.

II.2 Confirmation of utilization of the ITU-R evaluation guidelines in Report ITU-R M.2412

5G Infrastructure Association confirms that the evaluation guidelines provided in Report ITU-R M.2412-0 [3] have been utilized.

II.3 Documentation of any additional evaluation methodologies that are or might be developed by the Independent Evaluation Group to complement the evaluation guidelines

The following additional evaluation methodologies have been applied by this Evaluation Group:

- Updating of already available link-level and system-level simulators according to the submitted RITs and SRITs as well as to ITU-R requirements
- These link-level and system-level simulators have been calibrated with respect to externally available results.

II.4 Verification as per Report ITU-R M.2411 of the compliance templates and the self-evaluation for each candidate technology as indicated in A)

This Interim Evaluation Report is summarizing the available evaluation results by end of November 2019. The evaluation template is completed in Section III-2. These results confirm the self-evaluation of the proponent 3GPP.

II.4.1 Identify gaps/deficiencies in submitted material and/or self-evaluation

There were no gaps and deficiencies identified in the submission of 3GPP.

II.4.2 Identify areas requiring clarifications

During the evaluation process open issues were clarified with 3GPP experts on assumptions and simulation methodologies.

II.5 Assessment as per Reports ITU-R M.2410, ITU-R M.2411 and ITU-R M.2412 for each candidate technology as indicated in A)

In the following Sections details are provided on

- Detailed analysis/assessment and evaluation by the IEGs of the compliance templates submitted by the proponents per the Report ITU-R M.2411 section 5.2.4;

- Provide any additional comments in the templates along with supporting documentation for such comments;
- Analysis of the proponent’s self-evaluation by the IEG.

II.5.1 Analytical, inspection evaluation and simulation-based evaluation

II.5.1.1 Peak data rate

The ITU-R minimum requirements on peak data rate are given in [1]. The following requirements and remarks are extracted from [1]:

Peak data rate is the maximum achievable data rate under ideal conditions (in bit/s), which is the received data bits assuming error-free conditions assignable to a single mobile station, when all assignable radio resources for the corresponding link direction are utilized (i.e. excluding radio resources that are used for physical layer synchronization, reference signals or pilots, guard bands and guard times).

Peak data rate is defined for a single mobile station. In a single band, it is related to the peak spectral efficiency in that band. Let W denote the channel bandwidth and SE_p denote the peak spectral efficiency in that band. Then the user peak data rate R_p is given by:

$$R_p = W \times SE_p$$

Peak spectral efficiency and available bandwidth may have different values in different frequency ranges. In case bandwidth is aggregated across multiple bands, the peak data rate will be summed over the bands. Therefore, if bandwidth is aggregated across Q bands then the total peak data rate is:

$$R = \sum_{i=1}^Q W_i \times SE_{p_i}$$

where W_i and SE_{p_i} ($i = 1, \dots, Q$) are the component bandwidths and spectral efficiencies respectively.

The requirement is defined for the purpose of evaluation in the eMBB usage scenario.

The requirements for peak data are:

- *Downlink peak data rate is 20 Gbit/s.*
- *Uplink peak data rate is 10 Gbit/s.*

II.5.1.1.1 Basic parameters

Peak data rate expression is defined for downlink (DL) and uplink (UL) transmissions with TDD (Time Division Duplex) and FDD (Frequency Division Duplex) techniques as:

$$R = \sum_{j=1}^J \left(\alpha^{(j)} \cdot v_{Layers}^{(j)} \cdot Q_m^{(j)} \cdot f^{(j)} \cdot R_{max} \cdot \frac{N_{PRB}^{BW(j),\mu} \cdot 12}{T_s^\mu} \cdot (1 - OH^{(j)}) \right) \quad (1)$$

wherein:

J is the total number of aggregated carriers in a frequency band. It can reach integer values from 1 up to 16 in 5G NR and from 1 up to 32 in LTE.

$\alpha^{(j)}$ is the normalized scaling factor related to the proportion of resources used in the DL/UL ratio for the j component carrier. For FDD $\alpha^{(j)}=1$ for

DL and UL; and for TDD and other duplexing techniques for DL and UL, $\alpha^{(j)}$ is calculated based on the frame structure and the Slot Format Indicator (SFI).

In TDD DL, $\alpha^{(j)}$ considers the presence of Guard Period (GP) as part of the effective BW. As a consequence, the impact of GP has to be considered later in the overhead ($OH^{(j)}$) calculation.

$v_{Layers}^{(j)}$ is the maximum number of layers. For DL, it can reach integer values from 1 up to 8; and for UL, it is defined from 1 up to 4.

$Q_m^{(j)}$ is the maximum modulation order. It is set to 8 (256QAM) for 5G NR and to 10 (1024QAM) for LTE.

$f^{(j)}$ is the scaling factor used to reflect the capability mismatch between baseband and RF capability for both SA UE and NSA UE. Its use is also proposed to scale down the maximum throughput of NR UEs in EN-DC scenarios where there is LTE and NR hardware sharing.

$f^{(j)}$ is signaled per band and per band per band combination as per UE capability signalling.

There are two possible values, 1 or 0.75.

R_{max} is the maximum code rate. In 5G NR is set to 948/1024 while in LTE depends on the maximum Transport block size (TBS) and the number of useful data bits.

μ is the numerology set in 5G NR. In 5G NR it is defined in [10] and can reach integer values between 0 and 4. LTE unicast only considers numerologies equal to 0.

T_s^μ is the average OFDM symbol duration in a subframe for numerology, μ , i.e. $T_s^\mu = \frac{10^{-3}}{14 \cdot 2^\mu}$. It includes the impact of the CP insertion.

$N_{PRB}^{BW(j),\mu}$ is the maximum RB allocation in the available system bandwidth with numerology μ . In 5G NR, [11] specifies the UE supported maximum bandwidth for a given band or band combination. In LTE, the maximum RB allocation and available system bandwidth is specified in [12].

$OH^{(j)}$ is the overhead calculated as the average ratio of the number of REs occupied by L1/L2 control, synchronization signals, PBCH, reference signals and guard bands with respect to the total number of REs for the effective bandwidth in a 5G NR frame time product. More specific details about the overhead calculation in 5G NR and LTE are given in Annex A.

II.5.1.1.2 5G NR

II.5.1.1.2.1 Downlink

DL peak data rate is calculated for FDD (Table 3) and TDD modes (Table 4). For FDD, peak data rate is only calculated for the frequency range 1 (FR1) between 450 MHz and 6000 MHz in order to ensure minimum efficiency levels. For TDD, peak data rate is calculated in both FR1 and FR2 (24.25 GHz – 52.6 GHz). Peak data rate values have been calculated per component carrier with SISO and MIMO schemes and different aggregated component

carrier levels for both antenna configurations. Detailed parameter assumptions are given in Annex A.

II.5.1.1.2.1.1 FDD RIT

Considering an FDD configuration where all resources are assigned to DL transmissions, the obtained peak data rate values are calculated as follows:

TABLE 3
NR FDD DL peak data rate values (CC – component carrier)

SCS [kHz]		Per CC BW (MHz)	Peak data rate per CC, SISO (Gbit/s)	Number of Layers	Peak data rate per CC, MIMO (Gbit/s)	Number of CC	Aggregated peak data rate SISO (Gbit/s)	Aggregated peak data rate MIMO (Gbit/s)	Req. (Gbit/s)
FR1	15	50	0.30	8	2.40	16	4.81	38.54	20
	30	100	0.60		4.87		9.75	78.05	
	60	100	0.59		4.78		9.57	76.62	

II.5.1.1.2.1.2 TDD RIT

Following the same procedure, TDD DL peak data rate values are calculated:

TABLE 4
NR TDD DL peak data rate values (CC – component carrier)

SCS [kHz]		Per CC BW (MHz)	Peak data rate per CC SISO (Gbit/s)	Number of Layers	Peak data rate per CC MIMO (Gbit/s)	Number of CC	Aggregated peak data rate SISO (Gbit/s)	Aggregated peak data rate MIMO (Gbit/s)	Req. (Gbit/s)
FR1	15	50	0.22	8	1.80	16	3.61	28.94	20
	30	100	0.45		3.66		7.32	58.62	
	60	100	0.44		3.59		7.19	57.52	
FR2	60	200	0.89	6	5.39	16	13.19	86.31	20
	120	400	1.80		10.85		26.51	173.57	

II.5.1.1.2.2 Uplink

UL peak data rate is calculated for FDD (Table 5) and TDD modes (Table 6). For FDD, peak data rate is only evaluated in FR1. For TDD, peak data rate is calculated in both FR1 and FR2. Same SISO and MIMO assumptions with single and carrier aggregation levels are considered. The rest of assumptions is described in Annex A.

II.5.1.1.2.2.1 FDD RIT

TABLE 5

NR FDD UL RIT (CC – component carrier)

SCS [kHz]		Per CC BW (MHz)	Peak data rate per CC, SISO (Gbit/s)	Number of Layers	Peak data rate per CC, MIMO (Gbit/s)	Number of CC	Aggregated peak data rate SISO (Gbit/s)	Aggregated peak data rate MIMO (Gbit/s)	Req. (Gbit/s)
FR1	15	50	0.30	4	1.22	16	4.90	19.60	10
	30	100	0.62		2.49		9.99	39.99	
	60	100	0.62		2.49		9.98	39.54	

II.5.1.1.2.2.2 TDD RIT

TABLE 6

NR TDD UL RIT (CC – component carrier)

SCS [kHz]		Per CC BW (MHz)	Peak data rate per CC SISO (Gbit/s)	Number of Layers	Peak data rate per CC MIMO (Gbit/s)	Number of CC	Aggregated peak data rate SISO (Gbit/s)	Aggregated peak data rate MIMO (Gbit/s)	Req. (Gbit/s)
FR1	15	50	0.19	4	0.75	16	3.00	12.03	10
	30	100	0.38		1.52		6.11	24.46	
	60	100	0.37		1.50		6.02	24.08	
FR2	60	200	0.73	4	2.94	16	11.79	47.16	10
	120	400	1.47		5.91		23.64	94.57	

II.5.1.1.3 LTE

DL peak data rate is calculated in FDD (Table 7 and Table 9) and TDD modes (Table 8 and Table 10) for the frequency range set between 450 MHz and 6000 MHz. Data rate values have been obtained per component carrier with SISO and MIMO schemes and also with aggregated component carriers for both antenna configurations. Two different modulation orders and PDCCH symbol configurations have been considered for the calculation. The rest of parameters is described in Annex A.

II.5.1.1.3.1 Downlink

II.5.1.1.3.1.1 FDD RIT

TABLE 7

LTE FDD DL RIT (CC – component carrier)

Modulation Order	Number of PDCCH symbols	Peak data rate per CC, SISO (Gbit/s)	Peak data rate per CC, MIMO (Gbit/s)	Number of CC	Aggregated peak data rate SISO (Gbit/s)	Aggregated peak data rate MIMO (Gbit/s)	Req. (Gbit/s)
256 QAM	1	0.08	0.70	32	2.83	22.73	20
	2	0.08	0.67	32	2.69	21.53	
1024 QAM	1	0.10	0.86	32	3.47	27.82	
	2	0.10	0.82	32	3.29	26.36	

II.5.1.1.3.1.2 TDD RIT

TABLE 8

LTE TDD DL RIT (CC – component carrier)

Modulation Order	Number of PDCCH symbols	Peak data rate per CC, SISO (Gbit/s)	Peak data rate per CC, MIMO (Gbit/s)	Number of CC	Aggregated peak data rate SISO (Gbit/s)	Aggregated peak data rate MIMO (Gbit/s)	Req. (Gbit/s)
256 QAM	1	0.06	0.54	32	2.17	17.40	20
	2	0.06	0.51	32	2.06	16.52	
1024 QAM	1	0.08	0.66	32	2.64	21.12	
	2	0.08	0.64	32	2.52	20.65	

II.5.1.1.3.2 Uplink

UL peak data rate is calculated in FDD and TDD modes for the frequency range set between 450 MHz and 6000 MHz. Data rate values have been obtained per component carrier with SISO and MIMO schemes and also with aggregated component carriers for both antenna configurations. Only 256QAM modulation order is allowed in uplink transmissions. The rest of parameter assumptions is described in Annex A.

II.5.1.1.3.2.1 FDD RIT

TABLE 9

LTE FDD UL RIT (CC – component carrier)

Modulation Order	Peak data rate per CC, SISO (Gbit/s)	Peak data rate per CC, MIMO (Gbit/s)	Number of CC	Aggregated peak data rate SISO (Gbit/s)	Aggregated peak data rate MIMO (Gbit/s)	Req. (Gbit/s)
256 QAM	0.1	0.4	32	3.32	13.28	10

II.5.1.1.3.2.2 TDD RIT

TABLE 10

LTE TDD UL RIT (CC – component carrier)

Modulation Order	Peak data rate per CC, SISO (Gbit/s)	Peak data rate per CC, MIMO (Gbit/s)	Number of CC	Aggregated peak data rate SISO (Gbit/s)	Aggregated peak data rate MIMO (Gbit/s)	Req. (Gbit/s)
256 QAM	0.05	0.2	32	1.85	7.40	10

II.5.1.1.4 Observations

Observations are summarized in Table 11.

TABLE 11

Observations

ITU-R requirements	NR component RIT	LTE component RIT
Downlink: At least 20 Gbit/s	<p>For FDD, one component carrier is able to provide peak data rate values up to 600 Mbps with SISO antenna configurations and 4.87 Gbps with 8 layers in MIMO antenna configurations in frequencies between 450 MHz and 6 GHz. Considering TDD techniques, peak data rates up to 1.80 Gbps for SISO and 10.85 Gbps for MIMO 6 layers can be obtained for frequencies between 24.25 GHz and 52.6 GHz.</p> <p>By aggregating multiple component carriers, higher peak data rate values can be reached. Component carriers can be either contiguous or non-contiguous in the frequency domain. The</p>	<p>In FDD, one component carrier is able to provide peak data rate values up to 100 Mbps with SISO antenna configurations and 860 Mbps with 8 layers MIMO antenna configurations for frequencies between 450 MHz and 6 GHz. In TDD, peak data rates get reduced to 80 Mbps in SISO transmissions and 660 Mbps in MIMO 8 layers configurations. Higher peak data rate values can be reached by aggregating up to 32 component carriers contiguous or non-contiguous in the frequency domain. In particular, peak data rate values up to 3.47 Gbps and 27.82 Gbps can be achieved with FDD SISO</p>

	<p>number of component carriers has been set to the maximum, i.e. 16 component carriers. With this configuration, peak data rates up to 9.75 Gbps and 78.05 Gbps can be reached for FDD SISO and MIMO modes. In TDD, values up to 28.9 Gbps and 173.57 Gbps can be reached with SISO and MIMO configurations, respectively.</p> <p>The use of MIMO and carrier aggregation allows to meet the ITU-R peak data rate requirement. With carrier aggregation and SISO configuration, only TDD FR2 case meets the requirement. However, with carrier aggregation and MIMO configuration, all FDD and TDD cases reach peak data rates higher than 20 Gbps.</p>	<p>and MIMO configurations. In TDD, values up to 2.64 Gbps and 21.12 Gbps can be reached if 1024QAM is used in SISO and MIMO transmissions. LTE cannot meet the data rate requirements when 256QAM modulation is used in TDD.</p> <p>The use of MIMO (up to 8 layers) and carrier aggregation (up to 32 component carriers) are key factors to enable the fulfilment of the ITU-R peak data rate requirements. Additionally, the use of a high modulation order such as 1024QAM is crucial to meet the 20 Gbps peak data requirement in TDD. Despite these features, LTE cannot reach peak data rate values as high as 5G NR due to the frequency range limitation from 450 MHz to 6 GHz.</p>
<p>Uplink: At least 10 Gbit/s</p>	<p>For FDD, one component carrier is able to provide peak data rate values up to 620 Mbps with SISO antenna configurations and 2.49 Gbps with MIMO 4 layers configuration in frequency ranges between 450 MHz and 6 GHz. Considering TDD techniques for frequency ranges of 24.25 GHz - 52.6 GHz, peak data rates up to 1.47 Gbps for SISO and 5.91 Gbps for MIMO 4 layers can be obtained.</p> <p>By aggregating multiple component carriers, higher peak data rate values can also be reached for uplink transmissions. The number of component carriers has also been set to 16 component carriers. With this configuration, peak data rates up to 9.99 Gbps and 39.99 Gbps can be reached for FDD SISO and MIMO modes. In TDD, values up to 23.64 Gbps and 94.57 Gbps can be reached with SISO and MIMO configurations, respectively.</p> <p>As it can be seen, the use of MIMO and carrier aggregation techniques is also the key for uplink since it allows to meet the 10 Gbps ITU-R requirement.</p>	<p>In FDD, one component carrier is able to provide peak data rate values up to 100 Mbps with SISO and 400 Mbps with 4 layers MIMO antenna configuration in the range of frequencies between 450 MHz and 6 GHz. For TDD, peak data rates get halved to 50 Mbps for SISO and 200 Mbps for 4 layers MIMO configurations. The maximum modulation order for both configurations is 256QAM for the uplink side.</p> <p>Higher peak data rate values can be obtained by aggregating up to 32 component carriers. In particular, peak data rates up to 3.32 Gbps for SISO and 13.28 Gbps for MIMO can be obtained in FDD mode. On the other hand, TDD mode enables values up to 1.85 Gbps and 7.40 Gbps for SISO and MIMO respectively.</p> <p>The use of MIMO (up to 4 layers) and carrier aggregation (up to 32 carriers) allows to meet the peak data rate requirement in uplink transmissions for FDD mode. Nevertheless, when all resources are not assigned to the uplink side, i.e. TDD mode, carrier aggregation and MIMO are not enough to cover the 10 Gbps targeted value.</p>

II.5.2 Peak spectral efficiency

The ITU-R minimum requirements on peak spectral efficiency are given in [1]. The following requirements and remarks are extracted from [1]:

Peak spectral efficiency is the maximum data rate under ideal conditions normalised by channel bandwidth (in bit/s/Hz), where the maximum data rate is the received data bits assuming error-free conditions assignable to a single mobile station, when all assignable radio resources for the corresponding link direction are utilized (i.e. excluding radio resources that are used for physical layer synchronization, reference signals or pilots, guard bands and guard times).

This requirement is defined for the purpose of evaluation in the eMBB usage scenario.

The minimum requirements for peak spectral efficiencies are as follows:

- *Downlink peak spectral efficiency is 30 bit/s/Hz.*
- *Uplink peak spectral efficiency is 15 bit/s/Hz.*

These values were defined assuming an antenna configuration to enable eight spatial layers (streams) in the downlink and four spatial layers (streams) in the uplink. However, this does not form part of the requirement and the conditions for evaluation are described in Report ITU-R M.2412-0.

II.5.2.1 Basic parameters

Peak spectral efficiency is defined for DL and UL transmissions with FDD and TDD techniques as:

$$\eta_p = \frac{\gamma_p}{\alpha^{(j)} \cdot BW} \quad (2)$$

wherein:

γ_p is the peak data rate value obtained for each evaluated configuration;

$\alpha^{(j)}$ is the normalized scaling factor related to the proportion of resources used in the DL/UL ratio for the component carrier j. For FDD DL and UL $\alpha^{(j)}=1$; and for TDD and other duplexing for DL and UL, $\alpha^{(j)}$ is calculated based on the frame structure and the slot format indicator (SFI);

BW is the total bandwidth. It depends on the selected numerology, frequency range and duplexing technique.

II.5.2.2 5G NR

II.5.2.2.1 Downlink

DL peak spectral efficiency is calculated for both FDD (Table 12) and TDD techniques (Table 13). For FDD, peak spectral efficiency is only calculated for FR1 while for TDD, both FR1 and FR2 are considered. Peak spectral efficiency has only been calculated per component carrier with MIMO configurations. To enable the calculation, previous peak data rate values have considered. More details about the FDD and TDD frame structure are given in Annex A.

II.5.2.2.1.1 FDD RIT

TABLE 12
NR FDD DL RIT

SCS [kHz]	5 MHz	10 MHz	15 MHz	20 MHz	25 MHz	30 MHz	40 MHz	50 MHz	60 MHz	80 MHz	90 MHz	100 MHz	Req.	
FR1	15	X	X	X	X	X	X	X	48.1	–	–	–	30	
	30	X	X	X	X	X	X	X	X	X	X	X	48.7	30
	60	–	X	X	X	X	X	X	X	X	X	X	48.8	30

II.5.2.2.1.2 TDD RIT

TABLE 13
NR TDD DL RIT

SCS [kHz]	5 MHz	10 MHz	15 MHz	30 MHz	20 MHz	25 MHz	40 MHz	50 MHz	60 MHz	80 MHz	90 MHz	100 MHz	200 MHz	400 MHz	Req.
FR1	15	X	X	X	X	X	X	X	47.3	–	–	–	–	–	30
	30	X	X	X	X	X	X	X	X	X	X	47.9	–	–	30
	60	–	X	X	X	X	X	X	X	X	X	47.0	–	–	30
FR2	60	–	–	–	–	–	–	X	–	–	–	X	35.2	–	30
	120	–	–	–	–	–	–	X	–	–	–	X	X	35.4	30

II.5.2.2.2 Uplink

UL peak spectral efficiency is also calculated for both FDD (Table 14) and TDD (Table 15). Same assumptions about frequency ranges have been made. UL Peak spectral efficiency has only been calculated per component carrier with MIMO configurations. To enable the calculation, previous peak data rate values have been considered. More details about the FDD and TDD frame structure are given in Annex A.

II.5.2.2.2.1 FDD RIT

TABLE 14
NR FDD UL RIT

SCS [kHz]	5 MHz	10 MHz	15 MHz	30 MHz	20 MHz	25 MHz	40 MHz	50 MHz	60 MHz	80 MHz	90 MHz	100 MHz	Req.	
FR1	15	X	X	X	X	X	X	X	24.5	–	–	–	15	
	30	X	X	X	X	X	X	X	X	X	X	X	25.0	15
	60	–	X	X	X	X	X	X	X	X	X	X	24.7	15

II.5.2.2.2.2 TDD RIT

TABLE 15
NR TDD UL RIT

SCS [kHz]	5 MHz	10 MHz	15 MHz	30 MHz	20 MHz	25 MHz	40 MHz	50 MHz	60 MHz	80 MHz	90 MHz	100 MHz	200 MHz	400 MHz	Req.
FR1	15	X	X	X	X	X	X	X	23.6	-	-	-	-	-	15
	30	X	X	X	X	X	X	X	X	X	X	24.0	-	-	15
	60	-	X	X	X	X	X	X	X	X	X	23.6	-	-	15
FR2	60	-	-	-	-	-	-	X	-	-	-	X	23.1	-	15
	120	-	-	-	-	-	-	X	-	-	-	X	X	23.2	15

II.5.2.3 LTE

II.5.2.3.1 Downlink

DL peak spectral efficiency is calculated for both FDD (Table 16) and TDD techniques (Table 17) in the frequency range set between 450 MHz and 6 GHz. Peak spectral efficiency has been calculated per component carrier with MIMO configuration. To enable the calculation, previous peak data rate values have been considered. More details about the parameter configuration are given in Annex A.

II.5.2.3.1.1 FDD RIT

TABLE 16
LTE FDD DL RIT

Modulation Order	Number of PDCCH symbols	1.4 MHz	5 MHz	10 MHz	20 MHz	Req. (Bit/s/Hz)
256 QAM	1	X	X	X	35.52	30
	2	X	X	X	33.64	
1024 QAM	1	X	X	X	43.46	
	2	X	X	X	41.18	

II.5.2.3.1.2 TDD RIT

TABLE 17
LTE TDD DL RIT

Modulation Order	Number of PDCCH symbols	1.4 MHz	5 MHz	10 MHz	20 MHz	Req. (Bit/s/Hz)
256 QAM	1	X	X	X	34.79	30
	2	X	X	X	35.65	
1024 QAM	1	X	X	X	45.58	
	2	X	X	X	44.56	

II.5.2.3.2 Uplink

UL peak spectral efficiency is calculated for both FDD (Table 18) and TDD techniques (Table 19) in the frequency range set between 450 MHz and 6 GHz. Peak spectral efficiency has been calculated per component carrier with MIMO configuration considering different bandwidth values. To enable the calculation, previous peak data rate values have been considered. More details about the parameter configuration are given in Annex A.

II.5.2.3.2.1 FDD RIT

TABLE 18
LTE FDD UL RIT

Modulation Order	1.4 MHz	5 MHz	10 MHz	20 MHz	Req. (Bit/s/Hz)
256 QAM	X	X	X	20.74	15

II.5.2.3.2.2 TDD RIT

TABLE 19
LTE TDD UL RIT

Modulation Order	1.4 MHz	5 MHz	10 MHz	20 MHz	Req. (Bit/s/Hz)
256 QAM	X	X	X	18.81	15

II.5.2.4 Observations

Observations are summarized in Table 20.

TABLE 20
Observations

ITU-R requirements	NR component RIT	LTE component RIT
Downlink: At least 30 bits/s/Hz	One component carrier is able to provide peak spectral efficiency values up to 48.78 bps/Hz for FDD and up to 47.93 bps/Hz for TDD techniques thanks to the use of MIMO 8 layers configuration in FR1 . In FR2, spectral efficiency gets decreased to values around 35 bps/Hz due to the use of 6 MIMO layers instead of 8. Both configurations are able to meet the ITU-R requirement (30 bps/Hz) for all the evaluated bandwidths and numerologies.	One component carrier is able to provide peak spectral efficiency values up to 35.52 bps/Hz when 20 MHz bandwidth, MIMO 8 layers and 256QAM modulation order are configured in FDD transmissions . If the modulation order is increased to 1024QAM , values up to 43.46 bps/Hz can be reached. For TDD , 35.65 bps/Hz and 45.58 bps/Hz values can be achieved for 256QAM and 1024QAM respectively. Unlike peak data rate results, all configurations are able to meet the ITU-R requirement of 30 bps/Hz thanks to the bandwidth normalization done in the spectral efficiency calculation.
Uplink: At least 15 bits/s/Hz	One component carrier is able to provide peak spectral efficiency values up to 24.99 bps/Hz and 24.05 bps/Hz for both FDD and TDD techniques thanks to the use of with MIMO 4 layers configurations. All the numerology and bandwidth combinations are able to provide values above the ITU-R requirement, which is set to 15 bps/Hz.	One component carrier is able to provide peak spectral efficiency values up to 20.74 bps/Hz when 20 MHz bandwidth, MIMO 4 layers and 256QAM modulation order are configured in FDD transmissions. In TDD mode , values up to 18.81 bps/Hz can be achieved. Both modes meet the ITU-R requirement , set to 15 bps/Hz, thanks to the bandwidth normalization included in the spectral efficiency calculation.

II.5.3 User experienced data rate

The ITU-R minimum requirements on user experienced data rate are given in [1]. The following requirements and remarks are extracted from [1]:

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.

In case of one frequency band and one layer of transmission reception points (TRxP), the user experienced data rate could be derived from the 5th percentile user spectral efficiency through equation (3). Let W denote the channel bandwidth and SE_{user} denote the 5th percentile user spectral efficiency. Then the user experienced data rate, R_{user} is given by:

$$R_{user} = W \times SE_{user}$$

In case bandwidth is aggregated across multiple bands (one or more TRxP layers), the user experienced data rate will be summed over the bands.

This requirement is defined for the purpose of evaluation in the related eMBB test environment.

The target values for the user experienced data rate are as follows in the Dense Urban – eMBB test environment:

- *Downlink user experienced data rate is 100 Mbit/s.*
- *Uplink user experienced data rate is 50 Mbit/s.*

These values are defined assuming supportable bandwidth as described in Report ITU-R M.2412-0 for each test environment. However, the bandwidth assumption does not form part of the requirement. The conditions for evaluation are described in Report ITU-R M.2412-0.

According to [3], Section 7, the minimum requirements should be fulfilled by a RIT or jointly by different components of a SRIT. Hence, in the case of 3GPP’s proposal of both a pure 5G-NR RIT and an SRIT, where 5G-NR is augmented by an LTE component, it is sufficient to only verify, that the 5G RIT meets the minimum performance requirements. Accordingly, the evaluation for this and related KPIs analyzed by means of system-level simulation is restricted to 5G-NR RIT only. In the following “Source 1” and “Source 2” refer to the simulation assumptions in Annex B.

II.5.3.1 Basic parameters

As described above, the user experienced data rate is derived from the 5th percentile user spectral efficiency, which is discussed in Section III-4.

II.5.3.2 5G NR Dense Urban – eMBB

The evaluation of user experienced data rate is conducted for 5G NR TDD in Dense Urban – eMBB test environment. Both, FR1 and FR2 are considered. Detailed evaluation assumptions are based on 5th percentile user spectral efficiency evaluation and can be found in [1], [2].

II.5.3.2.1 Evaluation configuration A (CF = 4 GHz)

For Configuration A (single-band case), it is assumed that a component carrier of 40 MHz bandwidth is used for frame structure ‘DSUUD’. It is assumed that a component carrier of 40 MHz bandwidth for downlink and 100 MHz bandwidth for uplink is used for frame structure ‘DDDSU’. Additionally, carrier aggregation is applied to achieve the ITU-R requirement. The assumed aggregated system bandwidths in case of downlink and uplink are listed beside the evaluation results for NR TDD in Table 21 and Table 22.

TABLE 21
User experienced data rate for NR TDD with frame structure ‘DSUUD’ in Dense Urban – eMBB
Config. A (Source 1)

	System bandwidth [MHz]	User exp. data rate [Mbit/s]	Requirement [Mbit/s]
Downlink	600	104.6	100
Uplink	800	52.29	50

TABLE 22

User experienced data rate for NR TDD with frame structure ‘DDDSU’ in Dense Urban – eMBB Config. A (Source 2)

	System bandwidth [MHz]	User exp. data rate [Mbit/s]	Requirement [Mbit/s]
Downlink	320	111.45	100
Uplink	900	54.64	50

Table 23 and Table 24 show the results for NR FDD from two different contributions.

TABLE 23

User experienced data rate for NR FDD in Dense Urban – eMBB Config. A (Source 1)

	System bandwidth [MHz]	User exp. data rate [Mbit/s]	Requirement [Mbit/s]
Downlink	400	103.37	100
Uplink	680	51.0	50

TABLE 24

User experienced data rate for NR FDD in Dense Urban – eMBB Config. A (Source 2)

	System bandwidth [MHz]	User exp. data rate [Mbit/s]	Requirement [Mbit/s]
Downlink	240	103.2	100
Uplink	160	59.2	50

It is observed that NR TDD and FDD meet the downlink and uplink user experienced data rate requirements for Dense Urban – eMBB test environment in Configuration A.

II.5.3.2.2 Evaluation configuration B (CF = 30 GHz)

For Configuration B, it is assumed that a component carrier of 200 MHz is used. Additionally, carrier aggregation is applied to achieve the ITU-R requirement. The assumed aggregated system bandwidths in case of downlink and uplink are listed beside the evaluation results in Table 25.

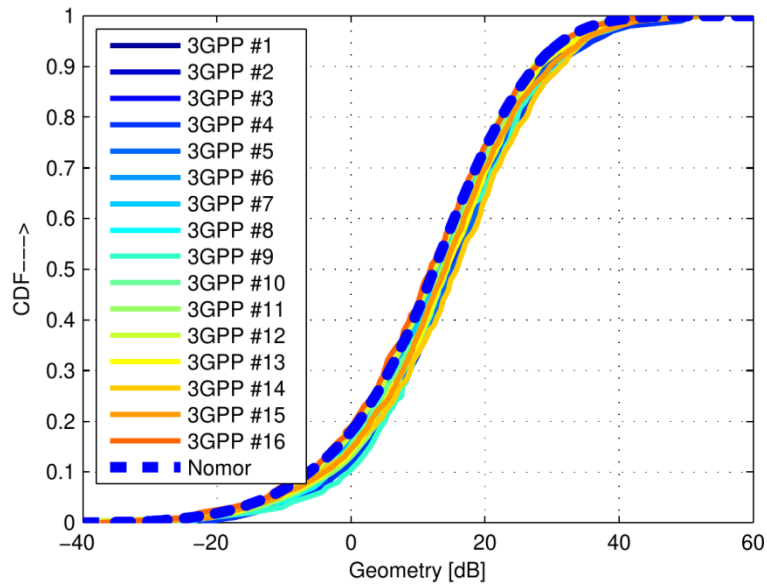
User experienced data rate for NR TDD with frame structure ‘DSUUD’ in Dense Urban – eMBB Config. B (Source 1)

	System bandwidth [MHz]	User exp. data rate [Mbit/s]	Requirement [Mbit/s]
Downlink	3 200	2.0	100
Uplink	3 200	2.13	50

It is observed that NR TDD neither meets the downlink nor the uplink ITU-R requirements in terms of user experienced data rate for Dense Urban – eMBB test environment in Configuration B. This is due to the fact that already the 5th percentile user requirement is by far not fulfilled, see Section III-4.2.2.2. The reason for this lies in the insufficient outdoor-to-

indoor link budget for users in buildings with high penetration loss. Here, inter-cell interference is not the limiting factor, but noise based on a limited transmit power budget of communication devices in both uplink and downlink. Considering the CDF of geometry received during the calibration process, see Figure 14 in [13], which is also reproduced as Figure 1 herein, this does not seem to be all that surprising because there are geometry values down to -30 dB. Besides, it is general knowledge that for large frequencies the penetration loss and pathloss is significantly higher and therefore it is difficult to achieve high spectral efficiency in scenarios with outdoor-to-indoor coverage.

FIGURE 1
Distribution of WB-SINR for Urban Config B, see Figure 14 of [13]



However, this is not considered to result in the 3GPP proposal failing to meet the ITU-R requirements for the dense urban scenario, since it is stated in [3], Section 8.4, that for test environments with multiple test configurations, a RIT/SRIT is considered to be in fulfillment of the requirements for this test environment, if the requirements are met in at least one of the test configurations.

II.5.3.2.3 Evaluation configuration C

For evaluation configuration C (multi-band), the system-level simulation is employed to evaluate the uplink user experienced data rate, where a TDD band on 30 GHz and a supplementary uplink (SUL) band on 4 GHz are used. In the evaluation, approximately 50% users with lower reference signal received power on TDD band (below -106 dBm) are offloaded to SUL band. The evaluation results of TDD+SUL bands are provided in Table 26 (Source 1) and Table 27 (Source 2).

In the evaluation, the subcarrier spacing with 15 kHz and a component carrier with 20 MHz are assumed in SUL band using FDD. In TDD band, the subcarrier space with 60 kHz and a component carrier with 80 MHz (Source 1) and 200 MHz (Source 2) are assumed. For Source 1 on each carrier, the simulation parameters shown in Annex B for Dense Urban configuration A and B were used for the carriers at 4 GHz and 30 GHz, respectively. For Source 2, simulation parameters are listed in Annex B. To meet the required user experienced data rate, multiple component carriers on either TDD band or SUL band are aggregated. The

required aggregated system bandwidth is given in Table 26 (Source 1) and Table 27 (Source 2).

TABLE 26
User experienced data rate in Dense Urban – eMBB Config. C
(NR TDD+SUL bands and Macro layer only) (Source 1)

	Frame structure	Assumed system bandwidth [MHz]	User experienced data rate [Mbps]	ITU Requirements [Mbps]
Uplink	4 GHz: full uplink; 30 GHz: DSUUD	4 GHz: 80 (for uplink) 30 GHz: 560	64.6	50

TABLE 27
User experienced data rate in Dense Urban – eMBB Config. C
(NR TDD+SUL bands and Macro layer only) (Source 2)

	Frame structure	Assumed system bandwidth [MHz]	User experienced data rate [Mbps]	ITU Requirements [Mbps]
Uplink	4 GHz: full uplink; 30 GHz: DDDSU with S slot =10DL:2GP:2UL	4 GHz: 100 (for uplink) 30 GHz: 1 200	51.39	50

It is observed that NR can meet the uplink user experienced data rate requirement for Dense Urban – eMBB test environment in evaluation configuration C.

For another mode of evaluation configuration C (single-band multi-layer), system-level simulation is employed to evaluate the downlink user experienced data rate, where in addition to a homogeneous dense urban macro-cell layout with fixed ISD of 200 m there is a micro-layer with three TRxPs randomly dropped per macro cell. Both network layers operate on the same carrier frequency in the 4 GHz band. With every micro TRxP, an additional set of 10 UEs are dropped aggregated within a radius of 20 m around the micro TRxP.

To meet the required user experienced data rate, multiple component carriers are aggregated. The required aggregated system bandwidth is given in Table 28. We note, that the bandwidth required to meet the performance requirement in terms of user experienced data rate is considerably higher than without the micro layer (c.f. Table 21). This result is a bit misleading and due to the definition of the KPI user experience data rate to be computed based on the 5%ile of the user spectral efficiency. It is to be expected that by increasing not only the density of the TRxP deployment in this already dense scenario, but at the same rate also the UE deployment, 5%ile UE spectral efficiency is not likely to be improved. Further analysis of the simulation results shows that the area traffic capacity for this scenario is in fact more than doubled compared to the pure-macro deployment with 10 UEs per macro cell.

TABLE 28

User experienced data rate in Dense Urban – eMBB Config. C (macro + micro layer at 4GHz) (Source 1)

	Frame structure	Assumed system bandwidth [MHz]	User experienced data rate [Mbps]	ITU Requirements [Mbps]
Downlink	DSUUD	1 200	104.71	100

It is observed that NR can meet the downlink user experienced data rate requirement for Dense Urban – eMBB test environment in evaluation configuration C with single band multi-layer deployment.

II.5.4 5th percentile user spectral efficiency

The ITU-R minimum requirements on 5th percentile user spectral efficiency are given in [1]. The following requirements and remarks are extracted from [1]:

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 of time, divided by the channel bandwidth and is measured in bit/s/Hz.

The channel bandwidth for this purpose is defined as the effective bandwidth times the frequency reuse factor, where the effective bandwidth is the operating bandwidth normalized appropriately considering the uplink/downlink ratio.

With $R_i(T_i)$ denoting the number of correctly received bits of user i , T_i the active session time for user i and W the channel bandwidth, the (normalized) user throughput of user i , r_i , is defined according to equation (4).

$$r_i = \frac{R_i(T_i)}{T_i \cdot W}$$

This requirement is defined for the purpose of evaluation in the eMBB usage scenario.

The minimum requirements for 5th percentile user spectral efficiency for various test environments are summarized in Table 12.

TABLE 12

5th percentile user spectral efficiency

Test environment	Downlink (bit/s/Hz)	Uplink (bit/s/Hz)
Indoor Hotspot – eMBB	0.3	0.21
Dense Urban – eMBB (NOTE 1)	0.225	0.15
Rural – eMBB	0.12	0.045

NOTE 1 – This requirement will be evaluated under Macro TRxP layer of Dense Urban – eMBB test environment as described in Report ITU-R M.2412-0.

The performance requirement for Rural-eMBB is not applicable to Rural-eMBB LMLC (low mobility large cell) which is one of the evaluation configurations under the Rural- eMBB test environment.

The conditions for evaluation including carrier frequency and antenna configuration are described in Report ITU-R M.2412-0 for each test environment.

Based on the reasoning given at the beginning of Section II.5.3 only 5G-NR RIT is evaluated.

II.5.4.1 Basic parameters

The 5th percentile user spectral efficiency (SE) is evaluated by system level simulations. The used simulator is calibrated against the results of the calibration which 3GPP performed in the context of self-evaluation, see [13]. System level simulations are performed for TDD technique.

Furthermore, as required in [3], the 5th percentile user spectral efficiency is assessed jointly with the average spectral efficiency using the same simulations.

II.5.4.2 5G NR

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 [3]. Further evaluation assumptions can be found in Appendix [1], [2].

II.5.4.2.1 Indoor Hotspot – eMBB

Two modes are considered for the Indoor Hotspot – eMBB test environment, namely operating with one or three sectors per site. For each mode, two configurations are applied. Evaluation configuration A with a carrier frequency of 4 GHz represents FR1, while evaluation configuration B with a carrier frequency of 30 GHz represents FR2. Configuration C for this scenario from ITU-R M.2412-0 [3] for operation at a carrier frequency of 70 GHz has not been evaluated, since the requirements are supported by the two other configurations, as shown by the results presented below.

II.5.4.2.1.1 Evaluation configuration A (CF = 4 GHz)

Table 29 and Table 30 show the evaluation results for NR TDD of downlink and uplink 5th percentile user spectral efficiency for Indoor Hotspot – eMBB Configuration A in both operation modes.

TABLE 29

5th percentile user SE for NR TDD with frame structure ‘DSUUD’ in Indoor Hotspot – eMBB Config. A (Source 1)

	5th percentile user SE [bit/s/Hz]		Requirement [bit/s/Hz]
Operation mode	1 sector per site	3 sectors per site	
Downlink	0.36	0.34	0.3
Uplink	0.49	0.31	0.21

TABLE 30

5th percentile user SE for NR TDD with frame structure ‘DDDSU’ in Indoor Hotspot – eMBB Config. A (Source 2)

Operation mode	5th percentile user SE [bit/s/Hz]		Requirement [bit/s/Hz]
	1 sector per site	3 sectors per site	
Downlink	0.39	0.35	0.3
Uplink	0.43	–	0.21

It is observed that NR TDD fulfills downlink and uplink 5th percentile user spectral efficiency requirement for Indoor Hotspot – eMBB test environment in Configuration A in both operation modes.

Table 31 and Table 32 are summarizing the results for NR FDD from different contributions.

TABLE 31

5th percentile user SE for NR FDD in Indoor Hotspot – eMBB Config. A (Source 1)

Operation mode	5th percentile user SE [bit/s/Hz]		Requirement [bit/s/Hz]
	1 sector per site	3 sectors per site	
Downlink	0.37	0.31	0.3
Uplink	0.48	0.28	0.21

TABLE 32

5th percentile user SE for NR FDD in Indoor Hotspot – eMBB Config. A (Source 2)

Operation mode	5th percentile user SE [bit/s/Hz]		Requirement [bit/s/Hz]
	1 sector per site	3 sectors per site	
Downlink	0.39	0.36	0.3
Uplink	0.55	0.59	0.21

It is observed that NR FDD fulfills the uplink 5th percentile user spectral efficiency requirement for Indoor Hotspot – eMBB test environment in Configuration A in both operation modes.

II.5.4.2.1.2 Evaluation configuration B (CF = 30 GHz)

Table 33 and Table 34 show the evaluation results for NR TDD of downlink and uplink 5th percentile user spectral efficiency for Indoor Hotspot – eMBB Configuration B in both operation modes.

TABLE 33

5th percentile user SE for NR TDD with frame structure ‘DSUUD’ in Indoor Hotspot – eMBB Config. B (Source 1)

	5th percentile user SE [bit/s/Hz]		Requirement [bit/s/Hz]
Operation mode	1 sector per site	3 sectors per site	
Downlink	0.48	0.34	0.3
Uplink	0.40	0.23	0.21

TABLE 34

5th percentile user SE for NR TDD with frame structure ‘DDDSU’ in Indoor Hotspot – eMBB Config. B (Source 2)

	5th percentile user SE [bit/s/Hz]		Requirement [bit/s/Hz]
Operation mode	1 sector per site	3 sectors per site	
Downlink	0.35	–	0.3
Uplink	0.41	–	0.21

Results for NR FDD are shown in Table 35.

TABLE 35

5th percentile user SE for NR FDD in Indoor Hotspot – eMBB Config. B (Source 1)

NR FDD are shown in	5th percentile user SE [bit/s/Hz]		Requirement [bit/s/Hz]
Operation mode	1 sector per site	3 sectors per site	
Downlink	0.39	0.30	0.3
Uplink	0.41	0.31	0.21

It is observed that NR TDD and FDD fulfil downlink and uplink 5th percentile user spectral efficiency requirement for Indoor Hotspot – eMBB test environment in Configuration B in both operation modes.

II.5.4.2.2 Dense Urban – eMBB

Configuration A (carrier frequency of 4 GHz) and Configuration B (carrier frequency of 30 GHz) are applied for the Dense Urban – eMBB test environment.

In addition to the system bandwidth determined in ITU-R M.2412-0 [3], downlink system-level simulations are performed with a larger component carrier bandwidth. The larger bandwidth provides a more efficient usage of bandwidth and a smaller overhead. The

simulation results with the larger bandwidth are used to calculate the user experienced data rate, see Section II.5.3.

II.5.4.2.2.1 Evaluation configuration A (CF = 4 GHz)

The downlink and uplink evaluation results for NR TDD for Dense Urban – eMBB Configuration A are provided in Table 36 and Table 37.

TABLE 36

5th percentile user SE for NR TDD with frame structure ‘DSUUD’ in Dense Urban – eMBB Config. A (Source 1)

	BW [MHz]	5th percentile user SE [bit/s/Hz]	Requirement [bit/s/Hz]
Downlink	20	0.30	0.225
	40	0.32	
Uplink	20	0.15	0.15

TABLE 37

5th percentile user SE for NR TDD with frame structure ‘DDDSU’ in Dense Urban – eMBB Config. A (Source 2)

	BW [MHz]	5th percentile user SE [bit/s/Hz]	Requirement [bit/s/Hz]
Downlink	20	0.39	0.225
	40	0.46	
Uplink	20	0.25	0.15

Table 38 and Table 39 are summarizing the NR FDD results from different contributions.

TABLE 38

5th percentile user SE for NR FDD in Dense Urban – eMBB Config. A (Source 1)

	BW [MHz]	5th percentile user SE [bit/s/Hz]	Requirement [bit/s/Hz]
Downlink	20	0.25	0.225
Uplink	20	0.3	0.15

TABLE 39

5th percentile user SE for NR FDD in Dense Urban – eMBB Config. A (Source 2)

	BW [MHz]	5th percentile user SE [bit/s/Hz]	Requirement [bit/s/Hz]
Downlink	10	0.43	0.225
Uplink	10	0.37	0.15

It is observed that NR TDD and FDD fulfil the downlink and uplink 5th percentile user spectral efficiency requirement for Dense Urban – eMBB test environment in Configuration A.

II.5.4.2.2.2 Evaluation configuration B (CF = 30 GHz)

The downlink and uplink evaluation results for NR FDD for Dense Urban – eMBB Configuration B are provided in Table 40.

TABLE 40

5th percentile user SE for NR FDD with in Dense Urban – eMBB Config. B (Source 1)

	BW [MHz]	5th percentile user SE [bit/s/Hz]	Requirement [bit/s/Hz]
Downlink	80	0.0004	0.225
Uplink	80	0.029	0.15

It is observed that NR FDD fulfils neither downlink nor uplink 5th percentile user spectral efficiency requirement for Dense Urban – eMBB test environment in Configuration B. Considering the CDF of geometry received during the calibration process, see Figure 14 in [13], this does not seem to be all that surprising because there are geometry values down to –30 dB (c.f. Section II.5.3.2.2). Besides, it is general knowledge that for large frequencies the penetration loss and pathloss is significantly higher and therefore it is difficult to achieve high spectral efficiency in scenarios with outdoor-to-indoor coverage. However, as pointed out above, fulfillment of the requirement in one of multiple configurations of a test environment is sufficient.

II.5.4.2.3 Rural – eMBB

For Rural – eMBB test environment two configurations in FR1 are applied, namely Configuration A with a carrier frequency of 700 MHz and Configuration B with carrier frequency of 4 GHz.

II.5.4.2.3.1 Evaluation configuration A (CF = 700 MHz)

The evaluation results for NR TDD for downlink and uplink in Rural – eMBB Configuration A are provided in Table 41 and Table 42.

TABLE 41

5th percentile user SE for NR TDD with frame structure ‘DSUUD’ in Rural – eMBB Config. A (Source 1)

	5th percentile user SE [bit/s/Hz]	Requirement [bit/s/Hz]
Downlink	0.21	0.12
Uplink	0.06	0.045

TABLE 42

5th percentile user SE for NR TDD with frame structure ‘DDDSU’ in Rural – eMBB Config. A (Source 2)

	5th percentile user SE [bit/s/Hz]	Requirement [bit/s/Hz]
Downlink	0.16	0.12
Uplink	0.09	0.045

Table 43 and Table 44 show the results for NR FDD from different contributions.

TABLE 43

5th percentile user SE for NR FDD in Rural – eMBB Config. A (Source 1)

	5th percentile user SE [bit/s/Hz]	Requirement [bit/s/Hz]
Downlink	0.19	0.12
Uplink	0.24	0.045

TABLE 44

5th percentile user SE for NR FDD in Rural – eMBB Config. A (Source 2)

	5th percentile user SE [bit/s/Hz]	Requirement [bit/s/Hz]
Downlink	0.15	0.12
Uplink	0.13	0.045

It is observed that NR TDD and FDD fulfil downlink and uplink 5th percentile user spectral efficiency requirement for Rural – eMBB test environment in Configuration A.

II.5.4.2.3.2 Evaluation configuration B (CF = 4 GHz)

The evaluation results for NR TDD for downlink and uplink in Rural – eMBB Configuration B are provided in Table 45 and Table 46.

TABLE 45

5th percentile user SE for NR TDD with frame structure ‘DSUUD’ in Rural – eMBB Config. B (Source 1)

	5th percentile user SE [bit/s/Hz]	Requirement [bit/s/Hz]
Downlink	0.23	0.12
Uplink	0.062	0.045

TABLE 46

5th percentile user SE for NR TDD with frame structure ‘DDDSU’ in Rural – eMBB Config. B (Source 2)

	5th percentile user SE [bit/s/Hz]	Requirement [bit/s/Hz]
Downlink	0.38	0.12
Uplink	0.13	0.045

NR FDD results are shown in Table 47 and Table 48 from different contributions.

TABLE 47

5th percentile user SE for NR FDD in Rural – eMBB Config. B (Source 1)

	5th percentile user SE [bit/s/Hz]	Requirement [bit/s/Hz]
Downlink	0.25	0.12
Uplink	0.12	0.045

TABLE 48

5th percentile user SE for NR FDD in Rural – eMBB Config. B (Source 2)

	5th percentile user SE [bit/s/Hz]	Requirement [bit/s/Hz]
Downlink	0.39	0.12
Uplink	0.21	0.045

It is observed that NR TDD and FDD fulfil downlink and uplink 5th percentile user spectral efficiency requirement for Rural – eMBB test environment in Configuration B.

II.5.4.2.3.3 Evaluation configuration C (CF = 700 MHz)

The evaluation results for downlink and uplink in Rural – eMBB Configuration C are provided in Table 49 to Table 52 from different contributions.

TABLE 49

5th percentile user SE for NR TDD with frame structure ‘DSUUD’ in Rural – eMBB Config. C (Source 1)

	5th percentile user SE [bit/s/Hz]	Requirement [bit/s/Hz]
Downlink	0.13	0.12
Uplink	0.075	0.045

TABLE 50

5th percentile user SE for NR TDD with frame structure ‘DDDSU’ in Rural – eMBB Config. C (Source 2)

	5th percentile user SE [bit/s/Hz]	Requirement [bit/s/Hz]
Downlink	0.195	0.12
Uplink	0.042	0.045

TABLE 51

5th percentile user SE for NR FDD in Rural – eMBB Config. C (Source 1)

	5th percentile user SE [bit/s/Hz]	Requirement [bit/s/Hz]
Downlink	0.13	0.12
Uplink	0.071	0.045

TABLE 52

5th percentile user SE for NR FDD in Rural – eMBB Config. C (Source 2)

	5th percentile user SE [bit/s/Hz]	Requirement [bit/s/Hz]
Downlink	0.182	0.12
Uplink	0.075	0.045

It is observed that NR TDD and FDD fulfil downlink and uplink 5th percentile user spectral efficiency requirement for Rural – eMBB test environment in Configuration C. In the case of Table 50 the performance is slightly below the requirement. However, as pointed out above, fulfillment of the requirement in one of multiple configurations of a test environment is sufficient.

II.5.5 Average spectral efficiency

The ITU-R minimum requirements on average spectral efficiency are given in [1]. The following requirements and remarks are extracted from [1]:

Average spectral efficiency³ 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 TRxPs and is measured in bit/s/Hz/TRxP. The channel bandwidth for this purpose is defined as the effective bandwidth times the frequency reuse factor, where the effective bandwidth is the operating bandwidth normalized appropriately considering the uplink/downlink ratio.

³ Average spectral efficiency corresponds to “spectrum efficiency” in Recommendation ITU-R M.2083.

Let $R_i(T)$ denote the number of correctly received bits by user i (downlink) or from user i (uplink) in a system comprising a user population of N users and M TRxPs. Furthermore, let W denote the channel bandwidth and T the time over which the data bits are received. The average spectral efficiency, SE_{avg} is then defined according to equation (5).

$$SE_{avg} = \frac{\sum_{i=1}^N R_i(T)}{T \cdot W \cdot M}$$

This requirement is defined for the purpose of evaluation in the eMBB usage scenario.

The minimum requirements for average spectral efficiency for various test environments are summarized in Table 13.

TABLE 13
Average spectral efficiency

Test environment	Downlink (bit/s/Hz/TRxP)	Uplink (bit/s/Hz/TRxP)
<i>Indoor Hotspot – eMBB</i>	9	6.75
<i>Dense Urban – eMBB (Note 1)</i>	7.8	5.4
<i>Rural – eMBB</i>	3.3	1.6
<i>NOTE 1 – This requirement applies to Macro TRxP layer of the Dense Urban – eMBB test environment as described in Report ITU-R M.2412-0.</i>		

The performance requirement for Rural-eMBB is also applicable to Rural-eMBB LMLC which is one of the evaluation configurations under the Rural- eMBB test environment. The details (e.g. 8 km inter-site distance) can be found in Report ITU-R M.2412-0.

The conditions for evaluation including carrier frequency and antenna configuration are described in Report ITU-R M.2412-0 for each test environment.

Based on the reasoning given at the beginning of Section II.5.3 only 5G-NR RIT is evaluated.

II.5.5.1 Basic parameters

The average spectral efficiency (SE) is evaluated by system level simulations. The used simulator is calibrated against the results of the calibration which 3GPP performed in the context of self-evaluation, see [13]. System level simulations are performed for TDD technique.

Furthermore, as required in [3] and as mentioned in Section III-4.1, the average spectral efficiency is assessed jointly with the 5th percentile user spectral efficiency using the same simulations.

II.5.5.2 5G NR

The evaluation of the average spectral efficiency is conducted for the three different test environments of eMBB. The test environments and evaluation configuration parameters are described in [3]. Further evaluation assumptions can be found in Appendix [1], [2].

II.5.5.2.1 Indoor Hotspot – eMBB

Two modes are considered for the Indoor Hotspot – eMBB test environment, namely operating with one or three sectors per site. For each mode, two configurations are applied. Evaluation configuration A with a carrier frequency of 4 GHz represents FR1, while evaluation configuration B with a carrier frequency of 30 GHz represents FR2. Configuration C for this scenario from ITU-R M.2412-0 [3] for operation at a carrier frequency of 70 GHz has not been evaluated, since the requirements are supported by the two other configurations, as shown by the results presented below.

In addition to the system bandwidth determined in ITU-R M.2412-0 [3], downlink system-level simulations are performed with a larger component carrier bandwidth. The larger bandwidth provides a more efficient usage of bandwidth and a smaller overhead. The simulation results with the larger bandwidth are used to calculate the area traffic capacity, see Section III-6.

II.5.5.2.1.1 Evaluation configuration A (CF = 4 GHz)

Table 53 and Table 54 provide the evaluation results for NR TDD of downlink and uplink average spectral efficiency for Indoor Hotspot – eMBB Configuration A in both operation modes.

TABLE 53

Average SE for NR TDD with frame structure ‘DSUUD’ in Indoor Hotspot – eMBB Config. A (Source 1)

Operation mode	BW [MHz]	Average SE [bit/s/Hz/TRxP]		Requirement [bit/s/Hz/TRxP]
		1 sector per site	3 sectors per site	
Downlink	20	13.6	12.9	9
	40	15.5	15.3	
Uplink	20	8.4	7.4	6.75

TABLE 54

Average SE for NR TDD with frame structure ‘DDDSU’ in Indoor Hotspot – eMBB Config. A (Source 2)

Operation mode	BW [MHz]	Average SE [bit/s/Hz/TRxP]		Requirement [bit/s/Hz/TRxP]
		1 sector per site	3 sectors per site	
Downlink	20	12.94	14.25	9
	40	15.23	16.77	
Uplink	20	7.62	-	6.75

Table 55 and Table 56 provide the NR FDD results from different contributions.

TABLE 55

Average SE for NR FDD in Indoor Hotspot – eMBB Config. A (Source 1)

Operation mode	BW [MHz]	Average SE [bit/s/Hz/TRxP]		Requirement [bit/s/Hz/TRxP]
		1 sector per site	3 sectors per site	
Downlink	20	12.14	12.17	9
Uplink	20	8.49	7.48	6.75

TABLE 56

Average SE for NR FDD in Indoor Hotspot – eMBB Config. A (Source 2)

Operation mode	BW [MHz]	Average SE [bit/s/Hz/TRxP]		Requirement [bit/s/Hz/TRxP]
		1 sector per site	3 sectors per site	
Downlink	20	12.78	15.26	9
Uplink	10	8.87	9.44	6.75

It is observed that NR TDD and FDD fulfil downlink and uplink average spectral efficiency requirement for Indoor Hotspot – eMBB test environment in Configuration A in both operation modes.

II.5.5.2.1.2 Evaluation configuration B (CF = 30 GHz)

The Table 57 and Table 58 provide the evaluation results for NR TDD of downlink and uplink average spectral efficiency for Indoor Hotspot – eMBB Configuration B in both operation modes.

TABLE 57

Average SE for NR TDD with frame structure ‘DSUUD’ in Indoor Hotspot – eMBB Config. B (Source 1)

Operation mode	BW [MHz]	Average SE [bit/s/Hz/TRxP]		Requirement [bit/s/Hz/TRxP]
		1 sector per site	3 sectors per site	
Downlink	80	14.7	11.2	9
	200	15.2	12.0	
Uplink	80	7.4	7.33	6.75

TABLE 58

Average SE for NR TDD with frame structure ‘DDDSU’ in Indoor Hotspot – eMBB Config. B (Source 2)

Operation mode	BW [MHz]	Average SE [bit/s/Hz/TRxP]		Requirement [bit/s/Hz/TRxP]
		1 sector per site	3 sectors per site	
Downlink	80	11.41	-	9
	200	13.27	-	
Uplink	80	7.04	-	6.75

NR FDD results are available in Table 59.

TABLE 59

Average SE for NR FDD in Indoor Hotspot – eMBB Config. B (Source 1)

Operation mode	BW [MHz]	Average SE [bit/s/Hz/TRxP]		Requirement [bit/s/Hz/TRxP]
		1 sector per site	3 sectors per site	
Downlink	80	13.06	10.66	9
Uplink	80	7.58	6.94	6.75

It is observed that NR TDD and FDD fulfil downlink and uplink average spectral efficiency requirement for Indoor Hotspot – eMBB test environment in Configuration B in both operation modes.

II.5.5.2.2 Dense Urban – eMBB

Configuration A (carrier frequency of 4 GHz) and Configuration B (carrier frequency 30 GHz) are applied for the Dense Urban – eMBB test environment.

II.5.5.2.2.1 Evaluation configuration A (CF = 4 GHz)

The downlink and uplink evaluation results for NR TDD for Dense Urban – eMBB Configuration A are provided in Table 60 and Table 61.

TABLE 60

Average SE for NR TDD with frame structure ‘DSUUD’ in Dense Urban – eMBB Config. A (Source 1)

	Average SE [bit/s/Hz/TRxP]	Requirement [bit/s/Hz/TRxP]
Downlink	16.9	7.8
Uplink	8.4	5.4

TABLE 61

Average SE for NR TDD with frame structure ‘DDDSU’ in Dense Urban – eMBB Config. A (Source 2)

	Average SE [bit/s/Hz/TRxP]	Requirement [bit/s/Hz/TRxP]
Downlink	12.75	7.8
Uplink	6.11	5.4

Table 62 and Table 63 are summarizing the NR FDD results from different contributions.

TABLE 63

Average SE for NR FDD in Dense Urban – eMBB Config. A (Source 1)

	Average SE [bit/s/Hz/TRxP]	Requirement [bit/s/Hz/TRxP]
Downlink	12.35	7.8
Uplink	8.5	5.4

TABLE 63

Average SE for NR FDD in Dense Urban – eMBB Config. A (Source 2)

	Average SE [bit/s/Hz/TRxP]	Requirement [bit/s/Hz/TRxP]
Downlink	12.86	7.8
Uplink	8.8	5.4

It is observed that NR TDD and FDD fulfil the downlink and uplink average spectral efficiency requirement for Dense Urban – eMBB test environment in Configuration A.

II.5.5.2.2.2 Evaluation configuration B (CF = 30 GHz)

The downlink and uplink evaluation results for NR TDD for Dense Urban – eMBB Configuration B are provided in Table 64.

TABLE 64

Average SE for NR FDD Dense Urban – eMBB Config. B (Source 1)

	Average SE [bit/s/Hz/TRxP]	Requirement [bit/s/Hz/TRxP]
Downlink	9.62	7.8
Uplink	7.42	5.4

It is observed that NR FDD fulfils downlink and uplink average spectral efficiency requirement for Dense Urban – eMBB test environment in Configuration B, due to very high spectral efficiency for UEs in advantageous channel conditions.

II.5.5.2.3 Rural – eMBB

For Rural – eMBB test environment two configurations in FR1 are applied, namely Configuration A with a carrier frequency of 700 MHz and Configuration B with carrier frequency of 4 GHz.

II.5.5.2.3.1 Evaluation configuration A (CF = 700 MHz)

The evaluation results for NR TDD for downlink and uplink in Rural – eMBB Configuration A are provided in Table 65 and Table 66.

TABLE 65

Average SE for NR TDD with frame structure ‘DSUUD’ in Rural – eMBB Config. A (Source 1)

	Average SE [bit/s/Hz/TRxP]	Requirement [bit/s/Hz/TRxP]
Downlink	8.45	3.3
Uplink	4.74	1.6

TABLE 66

Average SE for NR TDD with frame structure ‘DDDSU’ in Rural – eMBB Config. A (Source 2)

	Average SE [bit/s/Hz/TRxP]	Requirement [bit/s/Hz/TRxP]
Downlink	7.54	3.3
Uplink	5.05	1.6

NR FDD results are provided in Table 67 and Table 68 from different contributions.

TABLE 67

Average SE for NR FDD in Rural – eMBB Config. A (Source 1)

	Average SE [bit/s/Hz/TRxP]	Requirement [bit/s/Hz/TRxP]
Downlink	6.24	3.3
Uplink	4.1	1.6

TABLE 68

Average SE for NR FDD in Rural – eMBB Config. A (Source 2)

	Average SE [bit/s/Hz/TRxP]	Requirement [bit/s/Hz/TRxP]
Downlink	7.30	3.3
Uplink	4.29	1.6

It is observed that NR TDD and FDD fulfil downlink and uplink average spectral efficiency requirement for Rural – eMBB test environment in Configuration A.

II.5.5.2.3.2 Evaluation configuration B (CF = 4 GHz)

The evaluation results for NR TDD for downlink and uplink in Rural – eMBB Configuration B are provided in Table 69 and Table 70.

TABLE 69

Average SE for NR TDD with frame structure ‘DSUUD’ in Rural – eMBB Config. B (Source 1)

	Average SE [bit/s/Hz/TRxP]	Requirement [bit/s/Hz/TRxP]
Downlink	16.5	3.3
Uplink	7.01	1.6

TABLE 70

Average SE for NR TDD with frame structure ‘DDDSU’ in Rural – eMBB Config. B (Source 2)

	Average SE [bit/s/Hz/TRxP]	Requirement [bit/s/Hz/TRxP]
Downlink	15.14	3.3
Uplink	5.76	1.6

FDD results are shown in Table 71 and Table 72.

TABLE 71

Average SE for NR FDD in Rural – eMBB Config. B (Source 1)

	Average SE [bit/s/Hz/TRxP]	Requirement [bit/s/Hz/TRxP]
Downlink	14.67	3.3
Uplink	6.88	1.6

TABLE 72

Average SE for NR FDD in Rural – eMBB Config. B (Source 2)

	Average SE [bit/s/Hz/TRxP]	Requirement [bit/s/Hz/TRxP]
Downlink	15.25	3.3
Uplink	7.56	1.6

It is observed that NR TDD and FDD fulfil downlink and uplink average spectral efficiency requirement for Rural – eMBB test environment in Configuration B.

II.5.5.2.3.3 Evaluation configuration C (CF = 700 MHz)

The evaluation results for downlink and uplink in Rural – eMBB Configuration C are provided in Table 73 to Table 76 from different contributions.

TABLE 73

Average SE for NR TDD with frame structure ‘DSUUD’ in Rural – eMBB Config. C (Source 1)

	Average SE [bit/s/Hz/TRxP]	Requirement [bit/s/Hz/TRxP]
Downlink	6.86	3.3
Uplink	3.42	1.6

TABLE 74

Average SE for NR TDD with frame structure ‘DDDSU’ in Rural – eMBB Config. C (Source 2)

	Average SE [bit/s/Hz/TRxP]	Requirement [bit/s/Hz/TRxP]
Downlink	7.98	3.3
Uplink	3.53	1.6

TABLE 77

Average SE for NR FDD in Rural – eMBB Config. C (Source 1)

	Average SE [bit/s/Hz/TRxP]	Requirement [bit/s/Hz/TRxP]
Downlink	5.59	3.3
Uplink	3.59	1.6

TABLE 76

Average SE for NR FDD in Rural – eMBB Config. C (Source 2)

	Average SE [bit/s/Hz/TRxP]	Requirement [bit/s/Hz/TRxP]
Downlink	7.55	3.3
Uplink	4.10	1.6

It is observed that NR TDD and FDD fulfill downlink and uplink average spectral efficiency requirement for Rural – eMBB test environment in Configuration C.

II.5.6 Area traffic capacity

The ITU-R minimum requirements on area traffic capacity are given in [1]. The following requirements and remarks are extracted from [1]:

Area traffic capacity is the total traffic throughput served per geographic area (in Mbit/s/m²). The throughput is 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.

This can be derived for a particular use case (or deployment scenario) of one frequency band and one TRxP layer, based on the achievable average spectral efficiency, network deployment (e.g. TRxP (site) density) and bandwidth.

Let W denote the channel bandwidth and ρ the TRxP density (TRxP/m²). The area traffic capacity C_{area} is related to average spectral efficiency SE_{avg} through equation (6).

$$C_{area} = \rho \times W \times SE_{avg}$$

In case bandwidth is aggregated across multiple bands, the area traffic capacity will be summed over the bands.

This requirement is defined for the purpose of evaluation in the related eMBB test environment.

The target value for Area traffic capacity in downlink is 10 Mbit/s/m² in the Indoor Hotspot – eMBB test environment.

The conditions for evaluation including supportable bandwidth are described in Report ITU-R M.2412-0 for the test environment.

Based on the reasoning given at the beginning of Section II.5.3 only 5G-NR RIT is evaluated.

II.5.6.1 Basic parameters

As described above, the area traffic capacity is derived from the average spectral efficiency, which is discussed in Section III-5.

II.5.6.2 5G NR Indoor Hotspot – eMBB

The evaluation of average spectral efficiency is conducted for 5G NR TDD in Indoor Hotspot – eMBB test environment. There are two operation modes considered, namely 1 sector per scenario and 3 sectors per scenario. For each mode, two configurations are applied. Evaluation configuration A with a carrier frequency of 4 GHz represents FR1, while evaluation configuration B with a carrier frequency of 30 GHz represents FR2. Detailed evaluation assumptions are based on average spectral efficiency evaluation and can be found in [1], [2]. Configuration C for this scenario from ITU-R M.2412-0 [3] for operation at a carrier frequency of 70 GHz has not been evaluated, since the requirements are supported by the two other configurations, as shown by the results presented below.

II.5.6.2.1 Evaluation configuration A (CF = 4 GHz)

For Configuration A, it is assumed that a component carrier of 40 MHz bandwidth is used. Additionally, carrier aggregation is applied to achieve the ITU-R requirement. The assumed aggregated system bandwidths are given in Table 77 and Table 78.

TABLE 77

Area traffic capacity for NR TDD with frame structure ‘DSUUD’ in Indoor Hotspot – eMBB Config. A (Source 1)

	System bandwidth [MHz]	Area traffic capacity [Mbit/s/m²]	Requirement [Mbit/s/m²]
1 sector per site	600	10.60	10
3 sectors per site	200	10.04	10

TABLE 78

Area traffic capacity for NR TDD with frame structure ‘DDDSU’ in Indoor Hotspot – eMBB Config. A (Source 2)

	System bandwidth [MHz]	Area traffic capacity [Mbit/s/m²]	Requirement [Mbit/s/m²]
1 sector per site	440	10.15	10
3 sectors per site	160	12.19	10

Table 79 and Table 80 show NR FDD results from different contributions.

TABLE 79

Area traffic capacity for NR FDD in Indoor Hotspot – eMBB Config. A (Source 1)

	System bandwidth [MHz]	Area traffic capacity [Mbit/s/m²]	Requirement [Mbit/s/m²]
1 sector per site	400	11.77	10
3 sectors per site	120	12.04	10

TABLE 80

Area traffic capacity for NR FDD in Indoor Hotspot – eMBB Config. A (Source 2)

	System bandwidth [MHz]	Area traffic capacity [Mbit/s/m²]	Requirement [Mbit/s/m²]
1 sector per site	400	10.22	10
3 sectors per site	120	10.99	10

It is observed that NR TDD and FDD meet the ITU-R requirement in terms of area traffic capacity in downlink for Indoor Hotspot – eMBB test environment in Configuration A.

II.5.6.2.2 Evaluation configuration B (CF = 30 GHz)

For Configuration B, it is assumed that a component carrier of 200 MHz bandwidth is used. Additionally, carrier aggregation is applied to achieve the ITU-R requirement. The assumed aggregated system bandwidths are given in Table 81 and Table 82.

TABLE 81

Area traffic capacity for NR TDD with frame structure ‘DSUUD’ in Indoor Hotspot – eMBB Config. B (Source 1)

	System bandwidth [MHz]	Area traffic capacity [Mbit/s/m ²]	Requirement [Mbit/s/m ²]
1 sector per site	600	11.41	10
3 sectors per site	400	17.43	10

TABLE 82

Area traffic capacity for NR TDD with frame structure ‘DDDSU’ in Indoor Hotspot – eMBB Config. B (Source 2)

	System bandwidth [MHz]	Area traffic capacity [Mbit/s/m ²]	Requirement [Mbit/s/m ²]
1 sector per site	600	12.06	10

NR FDD results are shown in Table 83.

TABLE 83

Area traffic capacity for NR FDD in Indoor Hotspot – eMBB Config. B (Source 1)

	System bandwidth [MHz]	Area traffic capacity [Mbit/s/m ²]	Requirement [Mbit/s/m ²]
1 sector per site	400	12.63	10
3 sectors per site	200	15.17	10

It is observed that NR TDD and FDD meet the ITU-R requirement in terms of area traffic capacity in downlink for Indoor Hotspot – eMBB test environment in Configuration B.

II.5.7 User plane latency

The ITU-R minimum requirements on user plane latency are given in [1]. The following requirements and remarks are extracted from [1]:

User plane latency is the contribution of the radio network to the time from when the source sends a packet to when the destination receives it (in ms). It is defined as the one-way time it takes to successfully deliver an application layer packet/message from the radio protocol layer 2/3 SDU ingress point to the radio

protocol layer 2/3 SDU egress point of the radio interface in either uplink or downlink in the network for a given service in unloaded conditions, assuming the mobile station is in the active state.

This requirement is defined for the purpose of evaluation in the eMBB and URLLC usage scenarios.

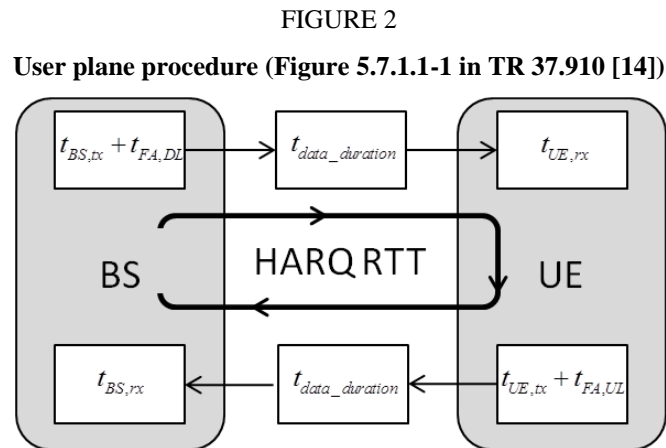
The minimum requirements for user plane latency are:

- 4 ms for eMBB
- 1 ms for URLLC

assuming unloaded conditions (i.e. a single user) for small IP packets (e.g. 0 byte payload + IP header), for both downlink and uplink.

II.5.7.1 Basic parameters / results NR Rel-15, user plane latency

As defined in Report ITU-R M.2410 [1], user plane latency is the contribution of the radio network to the time from when the source sends a packet to when the destination receives it (in ms). The user plane latency procedure is given in the Figure 2.



General assumptions followed by 3GPP are listed below:

- It is assumed that the packet arrives at any time of any OFDM symbol. In this case, the 0.5 symbol length is added as the “average symbol alignment time” at the beginning of the procedure.
- The transmission of PDCCH, PDSCH, PUCCH, PUSCH cannot be across the slot. Otherwise the transmission will wait for the next slot.
- The PDSCH/PUSCH allocation (transmission duration) of 2/4/7/14-os non-slot or slot are evaluated.
 - If the evaluation is for 14 OFDM Symbol length slot, then slot-based scheduling is used.
 - Otherwise non-slot-based scheduling is used.
- The resource mapping type A and B are considered, which impact the start timing of a transmission. Details on resource mapping mechanism can be found in TS 38.214 [15].
- It is assumed that PDCCH monitoring occasion occurs at every OFDM symbol in the evaluation.

The evaluation procedure is separated for downlink and uplink.

II.5.7.2 Downlink NR User Plane procedure

The detailed assumptions for user plane evaluation at the downlink are given in Table 84.

TABLE 84
DL user plane procedure for NR (Table 5.7.1.1.1-1 in TR 37.910 [14])

ID	Component	Notations	Value
1	DL data transfer	$T_1 = (t_{BS,tx} + t_{FA,DL}) + t_{DL_duration} + t_{UE,rx}$	
1.1	BS processing delay	$t_{BS,tx}$ The time interval between the data is arrived, and packet is generated.	$T_{proc,2}/2$, with $d_{2,1} = d_{2,2} = d_{2,3} = 0$. ($T_{proc,2}$ is defined in Section 6.4 of TS38.214) (NOTE 1, NOTE 2)
1.2	DL Frame alignment (transmission alignment)	$t_{FA,DL}$ It includes frame alignment time, and the waiting time for next available DL slot	$T_{FA} + T_{wait}$ T_{FA} is the frame alignment time within the current DL slot; T_{wait} is the waiting time for next available DL slot if the current slot is not DL slot.
1.3	TTI for DL data packet transmission	$t_{DL_duration}$	Length of one slot (14 OFDM symbol length) or non-slot (2/4/7 OFDM symbol length), depending on slot or non-slot selected in evaluation.
1.4	UE processing delay	$t_{UE,rx}$ The time interval between the PDSCH is received and the data is decoded;	$T_{proc,1}/2$ ($T_{proc,1}$ is defined in Section 5.3 of TS38.214), $d_{1,1}=0$; $d_{1,2}$ should be selected according to resource mapping type and UE capability. N_1 =the value with “No additional PDSCH DM-RS configured”. (NOTE 3)
2	HARQ retransmission	$T_{HARQ} = T_1 + T_2$ $T_2 = (t_{UE,tx} + t_{FA,UL}) + t_{UL_duration} + t_{BS,rx}$ (For Steps 2.1 to 2.4)	
2.1	UE processing delay	$t_{UE,tx}$ The time interval between the data is decoded, and ACK/NACK packet is generated.	$T_{proc,1}/2$ ($T_{proc,1}$ is defined in Section 5.3 of TS38.214), $d_{1,1}=0$; $d_{1,2}$ should be selected according to resource mapping type and UE capability. N_1 =the value with “No additional PDSCH DM-RS configured”. (NOTE 4)
2.2	UL frame alignment (transmission alignment)	$t_{FA,UL}$ It includes frame alignment time, and the waiting time for the next available UL slot	$T_{FA} + T_{wait}$ T_{FA} is the frame alignment time within the current UL slot; T_{wait} is the waiting time for next available UL slot if the current slot is not UL slot
2.3	TTI for ACK/NACK transmission	$t_{UL_duration}$	1 OFDM symbol
2.4	BS processing delay	$t_{BS,rx}$ The time interval between the ACK is received and the ACK is decoded.	$T_{proc,2}/2$ with $d_{2,1} = d_{2,2} = d_{2,3} = 0$. (NOTE 1, NOTE 5)
2.5	Repeat DL data transfer from 1.1 to 1.4	T_1	
-	Total one-way user plane latency for DL	$T_{UP} = T_1 + n \times T_{HARQ}$ where n is the number of re-transmissions ($n \geq 0$)	
<p>Note:</p> <p>1 The value is used for evaluation only; gNB processing delay may vary depending on implementation.</p> <p>2 For the case of a TDD band (30 kHz SCS) with an SUL band (15 kHz SCS), the value of this step is $T_{proc,2}(\mu = 30 \text{ kHz}) / 2$ for Initial transmission, and $T_{proc,2}(\mu = 15 \text{ kHz}) / 2$ for re-transmission.</p>			

ID	Component	Notations	Value
3	For the above case, the UE is processing PDSCH reception on TDD band with 30kHz SCS, and it is assumed that the value of this step is $T_{proc,1}(\mu = 30 \text{ kHz})/2$.		
4	For the above case, the value of this step is $T_{proc,1}(\mu = 15 \text{ kHz}) - T_{proc,1}(\mu = 30 \text{ kHz})/2$.		
5	For the above case, the value of this step is $T_{proc,2}(\mu = 15 \text{ kHz})/2$.		

II.5.7.2.1 Evaluation Methodology

The user plane latency was evaluated by means of Table 84 applying for each step the corresponding time delays.

Specifically, the calculation of BS processing delay (steps 1.1 and 2.4) and UE processing delay (steps 1.4 and 2.1) is realized by means of N_2 symbols duration (i.e. PUSCH preparation time) and N_1 symbols duration (i.e. PDSCH decoding time), described in the following two subsections.

II.5.7.2.1.1 UE PDSCH processing procedure time for Capability 1 and 2

N_1 symbols for UE Capability 1 are given by Table 5.3-1 of TS38.214 [15] which is rewritten below while $N_{1,0}$ equals to 13 or 14 (Table 85).

TABLE 85
PDSCH processing time for PDSCH processing capability 1

μ	PDSCH decoding time N_1 [symbols]	
	<i>dmrs-AdditionalPosition</i> = pos0 in <i>DMRS-DownlinkConfig</i> in both of <i>dmrs-DownlinkForPDSCH-MappingTypeA</i> , <i>dmrs-DownlinkForPDSCH-MappingTypeB</i>	<i>dmrs-AdditionalPosition</i> \neq pos0 in <i>DMRS-DownlinkConfig</i> in either of <i>dmrs-DownlinkForPDSCH-MappingTypeA</i> , <i>dmrs-DownlinkForPDSCH-MappingTypeB</i> or if the higher layer parameter is not configured
0	8	$N_{1,0}$
1	10	13
2	17	20
3	20	24

Our calculations were conducted with *dmrs-AdditionalPosition* = pos0.

For UE Capability 2, N_1 symbols are given by Table 5.3-2 of TS38.214 [15] which is rewritten below in Table 86.

TABLE 86
PDSCH processing time for PDSCH processing capability 2

μ	PDSCH decoding time N_1 [symbols]
	<i>dmrs-AdditionalPosition</i> = pos0 in <i>DMRS-DownlinkConfig</i> in both of <i>dmrs-DownlinkForPDSCH-MappingTypeA</i> , <i>dmrs-DownlinkForPDSCH-MappingTypeB</i>

0	3
1	4.5
2	9 for frequency range 1

II.5.7.2.1.2 UE PUSCH preparation procedure time for Capability 1 and 2

N_2 symbols are given for UE Capability 1 in Table 6.4-1 and for UE Capability 2 in Table 6.4-2 of TS38.214 [15]. Both tables are rewritten below in Table 87 and Table 88.

TABLE 87

PUSCH preparation time for PUSCH timing capability 1

μ	PUSCH preparation time N_2 [symbols]
0	10
1	12
2	23
3	36

TABLE 88

PUSCH preparation time for PUSCH timing capability 2

μ	PUSCH preparation time N_2 [symbols]
0	5
1	5.5
2	11 for frequency range 1

Based on the above values, time parameters $T_{proc,2}$ of steps 1.1 and 2.4 (defined in section 6.4, TS38.214, [15]) and $T_{proc,1}$ of steps 1.4 and 2.1 (defined in section 5.3, TS38.214, [15]) are calculated as follows:

$$T_{proc,2} = \max\left((N_2 + d_{2,1})(2048 + 144) \cdot \kappa 2^{-\mu} \cdot T_c, d_{2,2}\right) \quad (3)$$

$$T_{proc,1} = (N_1 + d_{1,1})(2048 + 144) \cdot \kappa 2^{-\mu} \cdot T_c \quad (4)$$

where,

$$d_{1,1} = d_{2,1} = d_{2,2} = 0,$$

$T_c = \frac{1}{(\Delta f_{max} \cdot N_f)}$ is the basic time unit for NR,

$$\Delta f_{max} = 480 \cdot 10^3 \text{ Hz},$$

$$N_f = 4096,$$

T_s is the basic time unit for LTE with $\kappa = \frac{T_s}{T_c} = 64$; and

μ the subcarrier spacing configuration (parameters definition given in section 4.1 of TS 38.211, [10]).

II.5.7.2.1.3 Resource mapping type A and B

The type A and type B resource allocation has different constraints that must be taken into account when calculating the control plane latency.

The constraints for the uplink are given in TS 38.214 Table 6.1.2.1-1 [15] (Table 89):

TABLE 89
Valid S and L combinations

PUSCH mapping type	Normal cyclic prefix			Extended cyclic prefix		
	S	L	S+L	S	L	S+L
Type A	0	{4,...,14}	{4,...,14}	0	{4,...,12}	{4,...,12}
Type B	{0,...,13}	{1,...,14}	{1,...,14}	{0,..., 11}	{1,...,12}	{1,...,12}

S = starting OFDM symbol relative to the start of the slot (numbered from 0 to 13).

L = number of consecutive OFDM symbols in scheduled PUSCH resource.

For mapping type A the uplink transmission always starts with OFDM symbol 0 in the slot, while the transmission can start at any OFDM symbol for mapping type B. For both mapping type A and B, the whole transmission must fit inside a slot (i.e. it cannot cross the slot boundary).

The constraints for the downlink are given in TS 38.214 Table 5.1.2.1-1 [15] (Table 90):

TABLE 90
Valid S and L combinations

PDSCH mapping type	Normal cyclic prefix			Extended cyclic prefix		
	S	L	S+L	S	L	S+L
Type A	{0,1,2,3} (Note 1)	{3,...,14}	{3,...,14}	{0,1,2,3} (Note 1)	{3,...,12}	{3,...,12}
Type B	{0,...,12}	{2,4,7}	{2,...,14}	{0,...,10}	{2,4,6}	{2,...,12}

Note 1: S = 3 is applicable only if *dmrs-TypeA-Position* = 3.

For mapping type A the downlink transmission can start at OFDM symbol 0, 1 or 2 (and 3 if *dmrs-TypeA-Position*=3) in the slot. In the calculations only S = 0, 1 or 2 was considered for Type A PDSCH. For mapping type B the transmission can start at any of the first 12 OFDM symbols (i.e. it cannot start at the last symbol) in the slot. For both mapping type A and B, the whole transmission must fit inside a slot (i.e. it cannot cross the slot boundary).

II.5.7.2.2 Downlink User Plane latency calculations

Based on the above analysis, our calculations in each step of the procedure are shown in Table 91.

TABLE 91

DL User Plane Latency calculation

ID	Latency contribution
1.1	$T_{proc,2}/2$ from eq. (3)
1.2	frame alignment time and the waiting time for next available DL slot with random starting points
1.3	Slot/non-slot duration = $\frac{M}{14} \cdot 2^{-\mu}$ ($M = 2,4,7,14$ OFDM symbols, $\mu =$ subcarriers spacing)
1.4	$T_{proc,1}/2$ from eq. (4)
2.1	$T_{proc,1}/2$ from eq. (4)
2.2	frame alignment time and the waiting time for next available UL slot with random starting points
2.3	1 OFDM symbol = $\frac{1}{14} \cdot 2^{-\mu}$
2.4	$T_{proc,2}/2$ from eq. (3)
2.5	Re-calculate steps 1.1 to 1.4
–	Random number of retransmissions

The calculations are repeated a large number of times with random starting points and number of retransmissions. Then the results are averaged. The calculations have been realized for the same configurations provided in TR 37.910 assuming an initial transmission error probability of $p=0$ and $p=0.1$. 5G PPP IMT2020 Evaluation Group results are given below in Table 92.

TABLE 92

DL user plane latency for NR FDD (ms)

DL user plane latency – NR FDD			UE capability 1				UE capability 2		
			SCS				SCS		
			15 kHz	30 kHz	60 kHz	120 kHz	15 kHz	30 kHz	60 kHz
Resource mapping Type A	M=4 (4OS non-slot)	p=0	1.33	0.74	0.54	0.34	1.02	0.55	0.36
		p=0.1	1.55	0.85	0.65	0.41	1.23	0.66	0.42
	M=7 (7OS non-slot)	p=0	1.55	0.85	0.59	0.36	1.23	0.66	0.42
		p=0.1	1.89	1.02	0.71	0.44	1.45	0.78	0.50
	M=14 (14OS slot)	p=0	2.18	1.16	0.75	0.44	1.86	0.98	0.57
		p=0.1	2.50	1.32	0.89	0.53	2.19	1.14	0.65
Resource mapping Type B	M=2 (2OS non-slot)	p=0	0.86	0.50	0.42	0.28	0.54	0.32	0.24
		p=0.1	1.03	0.60	0.51	0.34	0.64	0.38	0.29
	M=4 (4OS non-slot)	p=0	1.03	0.59	0.46	0.30	0.71	0.40	0.28
		p=0.1	1.23	0.70	0.56	0.36	0.83	0.47	0.34
	M=7 (7OS non-slot)	p=0	1.32	0.73	0.54	0.33	1.00	0.54	0.36
		p=0.1	1.54	0.86	0.64	0.40	1.16	0.65	0.42

For NR TDD of DDDSU (with S slot = 11DL:1GP:2UL), DSUUD (with S slot = 11DL:1GP:2UL), and DUDU (without GP) have been evaluated and given in Table 93 to Table 95.

TABLE 93
DL user plane latency for NR TDD (ms)
(Frame structure: DDDSU)

DL user plane latency – NR TDD (DDDSU)			UE capability 1			UE capability 2		
			SCS			SCS		
			15 kHz	30 kHz	60 kHz	15 kHz	30 kHz	60 kHz
Resource mapping Type A	M=4 (4OS non-slot)	p=0	1.55	0.83	0.60	1.20	0.67	0.41
		p=0.1	2.05	1.11	0.75	1.68	0.88	0.55
	M=7 (7OS non-slot)	p=0	1.77	0.94	0.64	1.42	0.75	0.47
		p=0.1	2.36	1.25	0.82	1.90	0.99	0.60
	M=14 (14OS slot)	p=0	2.79	1.44	0.88	2.47	1.26	0.72
		p=0.1	3.59	1.77	1.16	3.00	1.62	0.92
Resource mapping Type B	M=2 (2OS non-slot)	p=0	1.03	0.59	0.46	0.71	0.40	0.29
		p=0.1	1.24	0.71	0.57	0.85	0.49	0.35
	M=4 (4OS non-slot)	p=0	1.23	0.69	0.51	0.92	0.50	0.34
		p=0.1	1.47	0.83	0.64	1.09	0.60	0.40
	M=7 (7OS non-slot)	p=0	1.56	0.85	0.60	1.24	0.66	0.42
		p=0.1	1.89	1.02	0.72	1.48	0.79	0.50

TABLE 94
DL user plane latency for NR TDD (ms)
(Frame structure: DSUUD)

DL user plane latency – NR TDD (DSUUD)			UE capability 1				UE capability 2		
			SCS				SCS		
			15 kHz	30 kHz	60 kHz	120 kHz	15 kHz	30 kHz	60 kHz
Resource mapping Type A	M=4 (4OS non-slot)	p=0	1.96	1.06	0.69	0.41	1.62	0.85	0.51
		p=0.1	2.40	1.31	0.83	0.50	2.07	1.05	0.64
	M=7 (7OS non-slot)	p=0	2.16	1.13	0.74	0.43	1.82	0.95	0.56
		p=0.1	2.69	1.40	0.92	0.53	2.28	1.18	0.72
	M=14 (14OS slot)	p=0	3.37	1.77	1.04	0.59	3.06	1.58	0.87
		p=0.1	3.95	2.09	1.26	0.74	3.64	1.90	1.04
Resource mapping Type B	M=2 (2OS non-slot)	p=0	1.39	0.77	0.55	0.34	1.09	0.58	0.38
		p=0.1	1.66	0.91	0.68	0.41	1.23	0.67	0.45
	M=4 (4OS non-slot)	p=0	1.61	0.88	0.61	0.37	1.30	0.70	0.43
		p=0.1	1.91	1.03	0.73	0.44	1.51	0.82	0.51
	M=7 (7OS non-	p=0	1.97	1.05	0.70	0.42	1.65	0.87	0.52

	slot)	p=0.1	2.45	1.30	0.83	0.48	1.96	1.01	0.65
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TABLE 95
DL user plane latency for NR TDD (ms)
(Frame structure: DUDU)

DL user plane latency – NR TDD (DUDU)			UE capability 1				UE capability 2		
			SCS				SCS		
			15 kHz	30 kHz	60 kHz	120 kHz	15 kHz	30 kHz	60 kHz
Resource mapping Type A	M=4 (4OS non-slot)	p=0	1.85	0.98	0.67	0.39	1.49	0.80	0.49
		p=0.1	2.19	1.23	0.81	0.49	1.81	0.95	0.60
	M=7 (7OS non-slot)	p=0	2.04	1.08	0.71	0.42	1.73	0.90	0.53
		p=0.1	2.51	1.35	0.85	0.52	2.14	1.11	0.65
	M=14 (14OS slot)	p=0	2.71	1.42	0.87	0.50	2.35	1.23	0.69
		p=0.1	3.19	1.73	1.07	0.59	2.89	1.55	0.82
Resource mapping Type B	M=2 (2OS non-slot)	p=0	1.16	0.65	0.50	0.32	0.84	0.47	0.32
		p=0.1	1.36	0.77	0.60	0.38	1.05	0.57	0.37
	M=4 (4OS non-slot)	p=0	1.40	0.76	0.55	0.34	1.06	0.58	0.37
		p=0.1	1.62	0.89	0.67	0.41	1.28	0.68	0.44
	M=7 (7OS non-slot)	p=0	1.76	0.95	0.64	0.39	1.43	0.77	0.46
		p=0.1	2.05	1.18	0.76	0.47	1.65	0.87	0.57

II.5.7.3 Uplink NR User Plane procedure

The assumptions for the uplink procedure using a grant free transmission are given in Table 96.

TABLE 96
UL user plane procedure for NR (Table 5.7.1.2.2-1 in TR 37.910)

Step	Component	Notations	Value
1	UL data transfer	Table 96	$T_1 = (t_{UE,tx} + t_{FA,UL}) + t_{UL_duration} + t_{BS,rx}$
1.1	UE processing delay	$t_{UE,tx}$ The time interval between the data is arrived, and packet is generated;	$T_{proc,2}/2$ ($T_{proc,2}$ is defined in Section 6.4 of TS38.214), with $d_{2,1}=d_{2,2}=d_{2,3}=0$
1.2	UL Frame alignment (transmission alignment)	$t_{FA,UL}$ It includes frame alignment time, and the waiting time for next available UL slot	$T_{FA} + T_{wait}$, T_{FA} is the frame alignment time within the current UL slot, T_{wait} is the waiting time for next available UL slot if the current slot is not UL slot.
1.3	TTI for UL data packet transmission	$t_{UL_duration}$	Length of one slot (14 OFDM symbol length) or non-slot (2/4/7 OFDM symbol length), depending on slot or non-slot selected in evaluation.

Step	Component	Notations	Value
1.4	BS processing delay	$t_{BS,rx}$ The time interval between the PUSCH is received and the data is decoded;	$T_{proc,1}/2$ ($T_{proc,1}$ is defined in Section 5.3 of TS38.214), $d_{1,1}=0$; $d_{1,2}$ should be selected according to resource mapping type and UE capability. N_1 =the value with “No additional PDSCH DM-RS configured”; It is assumed that BS processing delay is equal to UE processing delay as for PDSCH (Note1)
2	HARQ retransmission	$T_{HARQ} = T_2 + T_1$ $T_2 = (t_{BS,tx} + t_{FA,DL}) + t_{DL_duration} + t_{UE,rx}$ (For Steps 2.1 to 2.4)	
2.1	BS processing delay	$t_{BS,tx}$ The time interval between the data is decoded, and PDCCH preparation	$T_{proc,1}/2$ ($T_{proc,1}$ is defined in Section 5.3 of TS38.214), $d_{1,1}=0$; $d_{1,2}$ should be selected according to resource mapping type and UE capability. N_1 =the value with “No additional PDSCH DM-RS configured”.
2.2	DL Frame alignment (transmission alignment)	$t_{FA,DL}$ It includes frame alignment time, and the waiting time for next available DL slot	$T_{FA} + T_{wait}$, T_{FA} is the frame alignment time within the current DL slot; T_{wait} is the waiting time for next available DL slot if the current slot is not DL slot;
2.3	TTI for PDCCH transmission	$t_{DL_duration}$	1 OFDM symbols for PDCCH scheduling the retransmission.
2.4	UE processing delay	$t_{UE,rx}$ The time interval between the PDCCH is received and decoded.	$T_{proc,2}/2$ ($T_{proc,2}$ is defined in Section 6.4 of TS38.214), with $d_{2,1}=d_{2,2}=d_{2,3}=0$
2.5	Repeat UL data transfer from 1.1 to 1.4	T_1	
	Total one-way user plane latency for UL	$T_{UP} = T_1 + n \times T_{HARQ}$ where n is the number of re-transmissions ($n \geq 0$)	
<p>Note:</p> <p>1 The value is used for evaluation only; gNB processing delay may vary depending on implementation.</p> <p>Note:</p> <p>2 The grant free transmission is assumed to use the following start symbols:</p> <p>a) For 2-symbol PUSCH, the start symbol can be symbols {0,2,4,6,8,10,12} for PUSCH resource mapping type B</p> <p>b) For 4-symbol PUSCH, the start symbol can be:</p> <p>i) For PUSCH resource mapping type B: symbols {0,7}</p> <p>ii) For PUSCH resource mapping type A: symbol 0;</p> <p>c) For 7-symbol PUSCH, the start symbol can be:</p> <p>i) For PUSCH resource mapping type B: symbols {0, 7}</p> <p>ii) For PUSCH resource mapping type A: symbol 0;</p> <p>d) For 14-symbol PUSCH, the start symbol can be at symbol #0 for PUSCH resource mapping type A and B.</p>			

II.5.7.3.1 Evaluation Methodology

The user plane UL procedure involves the same time parameters as in DL case, i.e. $T_{proc,2}$ and $T_{proc,1}$ given by eqs. (3) and (4) respectively. Starting symbols constraints at uplink, i.e. in PUSCH for resource mapping type A and B are given in Note 2 of Table 96 and for PDSCH are given in Table 90. Starting symbols constraints affect the waiting times involved in steps 1.2 and 2.2 of Table 96. Thus, our calculations in each step of the user plane procedure are shown in Table 97.

TABLE 97

UL User Plane Latency calculation

ID	Latency contribution
1.1	$T_{\text{proc},2}/2$ from eq. (3)
1.2	frame alignment time and the waiting time for next available UL slot with random starting points
1.3	Slot/non-slot duration = $\frac{M}{14} \cdot 2^{-\mu}$ ($M = 2,4,7,14$ OFDM symbols, $\mu =$ subcarriers spacing)
1.4	$T_{\text{proc},1}/2$ from eq. (4)
2.1	$T_{\text{proc},1}/2$ from eq. (4)
2.2	frame alignment time and the waiting time for next available DL slot with random starting points
2.3	1 OFDM symbol = $\frac{1}{14} \cdot 2^{-\mu}$
2.4	$T_{\text{proc},2}/2$ from eq. (3)
2.5	Re-calculate steps 1.1 to 1.4
–	Random number of retransmissions

II.5.7.3.2 Uplink User Plane latency calculations

The calculations are repeated a large number of times with random starting points and number of retransmissions and then the results are averaged. The calculations have been realized for the same configurations provided in TR 37.910 [14] assuming an initial transmission error probability of $p = 0$ and $p = 0.1$. 5G PPP IMT2020 Evaluation Group results are given in Table 98.

TABLE 98

UL user plane latency for NR FDD with grant free transmission (ms)

UL user plane latency (Grant free) – NR FDD			UE capability 1				UE capability 2		
			SCS				SCS		
			15 kHz	30 kHz	60 kHz	120 kHz	15 kHz	30 kHz	60 kHz
Resource mapping Type A	M=4 (4OS non-slot)	p=0	1.54	0.84	0.63	0.42	1.22	0.62	0.41
		p=0.1	1.75	1.00	0.74	0.51	1.43	0.73	0.48
	M=7 (7OS non-slot)	p=0	1.75	0.94	0.68	0.45	1.42	0.72	0.46
		p=0.1	1.97	1.11	0.79	0.53	1.65	0.83	0.55
	M=14 (14OS slot)	p=0	2.25	1.20	0.80	0.51	1.93	0.97	0.59
		p=0.1	2.59	1.37	0.94	0.59	2.26	1.15	0.67
Resource mapping Type B	M=2 (2OS non-slot)	p=0	0.96	0.55	0.48	0.35	0.64	0.33	0.27
		p=0.1	1.17	0.67	0.58	0.42	0.76	0.39	0.32
	M=4 (4OS non-slot)	p=0	1.28	0.71	0.56	0.39	0.96	0.49	0.35
		p=0.1	1.50	0.85	0.67	0.47	1.14	0.58	0.41
	M=7 (7OS non-slot)	p=0	1.50	0.82	0.62	0.42	1.18	0.60	0.40
		p=0.1	1.74	0.96	0.73	0.50	1.37	0.69	0.47
	M=14 (14OS slot)	p=0	2.25	1.20	0.80	0.51	1.92	0.97	0.59
		p=0.1	2.57	1.37	0.94	0.60	2.28	1.14	0.67

For NR TDD, DDDSU (with S slot = 11DL:1GP:2UL), DSUUD (with S slot = 11DL:1GP:2UL), and DUDU (without GP) configurations have been evaluated and given in Table 99 to Table 101.

TABLE 99
UL user plane latency for NR TDD with grant free transmission (ms)
(Frame structure: DDDSU)

UL user plane latency – NR TDD (DDDSU)			UE capability 1			UE capability 2		
			SCS			SCS		
			15 kHz	30 kHz	60 kHz	15 kHz	30 kHz	60 kHz
Resource mapping Type A	M=4 (4OS non-slot)	p=0	3.56	1.87	1.13	3.15	1.63	0.91
		p=0.1	4.00	2.12	1.26	3.73	1.86	1.01
	M=7 (7OS non-slot)	p=0	3.76	1.95	1.17	3.35	1.69	0.96
		p=0.1	4.37	2.21	1.36	3.97	2.02	1.11
	M=14 (14OS slot)	p=0	4.27	2.25	1.31	3.97	1.94	1.11
		p=0.1	4.79	2.46	1.58	4.30	2.26	1.23
Resource mapping Type B	M=2 (2OS non-slot)	p=0	2.51	1.33	0.87	2.18	1.10	0.66
		p=0.1	3.03	1.58	1.01	2.73	1.36	0.80
	M=4 (4OS non-slot)	p=0	3.09	1.61	1.01	2.76	1.38	0.80
		p=0.1	3.63	1.87	1.16	3.32	1.66	0.93
	M=7 (7OS non-slot)	p=0	3.30	1.73	1.07	2.99	1.49	0.85
		p=0.1	3.87	1.98	1.20	3.56	1.77	0.99

TABLE 100
UL user plane latency for NR TDD with grant free transmission (ms)
(Frame structure: DSUUD)

UL user plane latency – NR TDD (DSUUD)			UE capability 1				UE capability 2		
			SCS				SCS		
			15 kHz	30 kHz	60 kHz	120 kHz	15 kHz	30 kHz	60 kHz
Resource mapping Type A	M=4 (4OS non-slot)	p=0	2.75	1.46	0.94	0.57	2.35	1.20	0.68
		p=0.1	3.41	1.72	1.05	0.67	2.93	1.48	0.85
	M=7 (7OS non-slot)	p=0	2.97	1.56	0.96	0.60	2.60	1.33	0.76
		p=0.1	3.48	1.84	1.12	0.71	3.29	1.64	0.90
	M=14 (14OS slot)	p=0	3.49	1.79	1.08	0.66	3.11	1.59	0.90
		p=0.1	3.98	2.02	1.29	0.83	3.72	1.89	1.04
Resource mapping Type B	M=2 (2OS non-slot)	p=0	1.82	0.98	0.70	0.46	1.51	0.76	0.48
		p=0.1	2.13	1.24	0.83	0.53	1.72	0.88	0.58
	M=4 (4OS non-slot)	p=0	2.32	1.25	0.83	0.52	2.03	1.02	0.61
		p=0.1	2.86	1.49	0.95	0.60	2.26	1.25	0.75
	M=7 (7OS non-	p=0	2.54	1.34	0.87	0.55	2.22	1.13	0.66
		p=0.1	3.11	1.61	1.01	0.67	2.89	1.48	0.85

	slot)	p=0.1	3.10	1.60	1.01	0.65	2.76	1.38	0.79
	M=14 (14OS slot)	p=0	3.45	1.81	1.10	0.66	3.14	1.58	0.89
		p=0.1	4.03	2.08	1.30	0.80	3.68	1.84	1.03

TABLE 101

**UL user plane latency for NR TDD with grant free transmission (ms)
(Frame structure: DUDU)**

UL user plane latency – NR TDD (DU)			UE capability 1				UE capability 2		
			SCS				SCS		
			15 kHz	30 kHz	60 kHz	120 kHz	15 kHz	30 kHz	60 kHz
Resource mapping Type A	M=4 (4OS non-slot)	p=0	2.01	1.09	0.75	0.48	1.70	0.86	0.54
		p=0.1	2.46	1.34	0.85	0.57	1.96	0.97	0.64
	M=7 (7OS non-slot)	p=0	2.25	1.19	0.80	0.51	1.90	0.97	0.60
		p=0.1	2.66	1.43	0.97	0.59	2.19	1.09	0.72
	M=14 (14OS slot)	p=0	2.76	1.43	0.93	0.58	2.40	1.23	0.72
		p=0.1	3.16	1.71	1.15	0.68	2.84	1.44	0.81
Resource mapping Type B	M=2 (2OS non-slot)	p=0	1.26	0.70	0.55	0.39	0.93	0.47	0.34
		p=0.1	1.46	0.82	0.66	0.47	1.14	0.57	0.40
	M=4 (4OS non-slot)	p=0	1.66	0.90	0.66	0.44	1.35	0.68	0.44
		p=0.1	1.97	1.05	0.77	0.52	1.54	0.78	0.52
	M=7 (7OS non-slot)	p=0	1.88	1.01	0.71	0.47	1.55	0.78	0.50
		p=0.1	2.19	1.22	0.83	0.54	1.77	0.90	0.60
	M=14 (14OS slot)	p=0	2.75	1.45	0.93	0.58	2.43	1.22	0.71
		p=0.1	3.22	1.68	1.10	0.69	2.88	1.43	0.83

II.5.7.4 LTE Rel-15 User Plane Latency

The LTE user plane latency evaluation follows a procedure similar to NR. The detailed assumptions for DL and UL are given below in separate Sections II.5.7.4.1 and II.5.7.4.2.

II.5.7.4.1 Downlink LTE UP Latency calculations

The assumptions at the downlink procedure are given in Table 102:

TABLE 102

DL user plane procedure for LTE (Table 5.7.1.2.1-1 in TR 37.910)

ID	Component	Notations	Value
1	DL data transfer	$T_1 = (t_{BS,tx} + t_{FA,DL}) + t_{DL_duration} + t_{UE,rx}$	
1.1	BS processing delay	$t_{BS,tx}$ The time interval between the data is arrived, and packet is generated.	1.5 TTI

ID	Component	Notations	Value
1.2	DL Frame alignment (transmission alignment)	$t_{FA,DL}$ It includes frame alignment time, and the waiting time for next available DL slot	$T_{FA} + T_{wait}$, T_{FA} is the frame alignment time within the current DL slot; T_{wait} is the waiting time for next available DL slot if the current slot is not DL slot.
1.3	TTI for DL data packet transmission	$t_{DL_duration}$	1 TTI
1.4	UE processing delay	$t_{UE,rx}$ The time interval between the PDSCH is received and the data is decoded;	1.5 TTI
2	HARQ retransmission	$T_{HARQ} = T_1 + T_2$ $T_2 = (t_{UE,tx} + t_{FA,UL}) + t_{UL_duration} + t_{BS,rx}$ (For Steps 2.1 to 2.4)	
2.1	UE processing delay	$t_{UE,tx}$ The time interval between the data is decoded, and ACK/NACK packet is generated.	1.5 TTI
2.2	UL frame alignment (transmission alignment)	$t_{FA,UL}$ It includes frame alignment time, and the waiting time for the next available UL slot	$T_{FA} + T_{wait}$, T_{FA} is the frame alignment time within the current UL slot; T_{wait} is the waiting time for next available UL slot if the current slot is not UL slot
2.3	TTI for ACK/NACK transmission	$t_{UL_duration}$	1 OFDM symbol
2.4	BS processing delay	$t_{BS,rx}$ The time interval between the ACK is received and the ACK is decoded.	1.5 TTI
2.5	Repeat DL data transfer from 1.1 to 1.4	T_1	
-	Total one-way user plane latency for DL	$T_{UP} = T_1 + n \times T_{HARQ}$ where n is the number of re-transmissions ($n \geq 0$) <i>Average</i> $T_{UP} = T_1 + p \times T_{HARQ}$ where p is the probability of re-transmissions	
NOTE: For short TTI, it is assumed that PDCCH and sPDCCH can both schedule sPDSCH such that there is no additional waiting time for PDCCH if the data arrives within the PDCCH region. In addition, sPDCCH and sPDSCH can be frequency multiplexed.			

Based on the above assumptions, DL user plane latency has been calculated for FDD and TDD (Table 103). For FDD, short TTIs are considered with 2 OFDM Symbols (OS), 3OS and 7OS for initial transmission error probability of $p = 0$ and $p = 0.1$.

TABLE 103

DL user plane latency for LTE FDD

TTI duration	Error probability	DL UP latency (ms)
20S	$p=0$	0.69
	$p=0.1$	0.82
30S	$p=0$	1.23
	$p=0.1$	1.45
70S	$p=0$	2.32
	$p=0.1$	2.75

For TDD, 70S TTI is considered for DSUDD and DSUUD configurations. The average user plane is provided for a large number of calculations with initial transmission error probability of $p=0$ and $p=0.1$ (Table 104).

TABLE 104

DL user plane latency for LTE TDD

TTI duration	Criterion	Error probability	DL UP latency (ms)	
			DSUDD (Cfg.1)	DSUUD (Cfg.2)
70S	Average case	$p=0$	2.48	2.81
		$p=0.1$	3.14	3.38

II.5.7.4.2 Uplink LTE UP Latency calculations

The assumptions at the uplink procedure are given in the Table 105.

TABLE 105

UL user plane procedure for LTE (Table 5.7.1.2.2-1 in TR 37.910)

Step	Component	Notations	Value
1	UL data transfer	$T_1 = (t_{UE,tx} + t_{FA,UL}) + t_{UL_duration} + t_{BS,rx}$	
1.1	UE processing delay	$t_{UE,tx}$ The time interval between the data is arrived, and packet is generated;	1.5 TTI
1.2	UL Frame alignment (transmission alignment)	$t_{FA,UL}$ It includes frame alignment time, and the waiting time for next available UL slot	$T_{FA} + T_{wait}$, T_{FA} is the frame alignment time within the current UL slot. T_{wait} is the waiting time for next available UL slot if the current slot is not UL slot.
1.3	TTI for UL data packet transmission	$t_{UL_duration}$	1 TTI
1.4	BS processing delay	$t_{BS,rx}$ The time interval between the PUSCH is received and the data is decoded;	1.5 TTI

Step	Component	Notations	Value
2	HARQ retransmission	$T_{\text{HARQ}} = T_2 + T_1$ $T_2 = (t_{\text{BS,tx}} + t_{\text{FA,DL}}) + t_{\text{DL_duration}} + t_{\text{UE,rx}}$ (For Steps 2.1 to 2.4)	
2.1	BS processing delay	$t_{\text{BS,tx}}$ The time interval between the data is decoded, and PDCCH preparation	1.5 TTI
2.2	DL Frame alignment (transmission alignment)	$t_{\text{FA,DL}}$ It includes frame alignment time, and the waiting time for next available DL slot	$T_{\text{FA}} + T_{\text{wait}}$, T_{FA} is the frame alignment time within the current DL slot; T_{wait} is the waiting time for next available DL slot if the current slot is not DL slot
2.3	TTI for PDCCH transmission	$t_{\text{DL_duration}}$	1 OFDM symbols for PDCCH scheduling the retransmission.
2.4	UE processing delay	$t_{\text{UE,rx}}$ The time interval between the PDCCH is received and the decoded.	1.5 TTI
2.5	Repeat UL data transfer from 1.1 to 1.4	T_1	
	Total one-way user plane latency for UL	$T_{\text{UP}} = T_1 + n \times T_{\text{HARQ}}$ where n is the number of re-transmissions ($n \geq 0$) <i>Average</i> $T_{\text{UP}} = T_1 + p \times T_{\text{HARQ}}$ where p is the probability of re-transmissions	

Based on the above assumptions, UL user plane latency has been calculated for FDD and TDD (Table 106). For FDD, short TTIs are considered with 2OS, 3OS and 7OS for initial transmission error probability of $p=0$ and $p=0.1$.

TABLE 106

UL user plane latency for LTE FDD

TTI duration	Error probability	UL UP latency (ms)
2OS	$p=0$	0.69
	$p=0.1$	0.83
3OS	$p=0$	1.26
	$p=0.1$	1.48
7OS	$p=0$	2.32
	$p=0.1$	2.82

For TDD, 7OS TTI is considered for DSUDD and DSUUD configurations. The average user plane is provided for a large number of calculations with initial transmission error probability of $p=0$ and $p=0.1$ (Table 107).

TABLE 107

UL user plane latency for LTE TDD

TTI duration	Criterion	Error probability	UL UP latency (ms)	
			DSUDD (Cfg.1)	DSUUD (Cfg.2)
70S	Average case	$p=0$	4.11	3.35
		$p=0.1$	4.70	3.91

II.5.7.5 Conclusions

For NR FDD and TDD, the calculated user plane latency at the downlink was below the ITU IMT2020 requirement of 4 ms in all cases. The lower latency values were observed for FDD, 120 kHz subcarrier spacing, UE Capability 1 or 60 kHz subcarrier spacing, UE Capability 2. The minimum latency approaches 0.25 ms.

At the uplink, for NR TDD, DDDSU configuration, user plane latency resulted to values larger than 4 ms in few cases with 15 kHz spacing (Table 99). However, this is rather expected since the DDDSU configuration offers limited UL resources. In all other cases, for FDD and TDD the latency was below 4ms. The lower values were observed again for FDD, 120 kHz subcarrier spacing, UE Capability 1 or 60 kHz subcarrier spacing, UE Capability 2 with the minimum latency approaching 0.30 ms.

For LTE FDD and TDD, the calculated user plane latency at the downlink was below the ITU IMT2020 requirement of 4 ms in all cases. At the uplink, TDD with DSUDD configuration results to latency values larger than 4 ms (similar to NR case). In all other cases, for FDD and TDD the latency was below 4 ms.

In both the downlink and uplink procedures, LTE achieves user plane latency lower than 1ms only with 20S TTI.

II.5.8 Control plane latency

The ITU-R minimum requirements on control plane are given in [1]. The following requirements and remarks are extracted from [1]:

Control plane latency refers to the transition time from a most “battery efficient” state (e.g. Idle state) to the start of continuous data transfer (e.g. Active state).

This requirement is defined for the purpose of evaluation in the eMBB and URLLC usage scenarios.

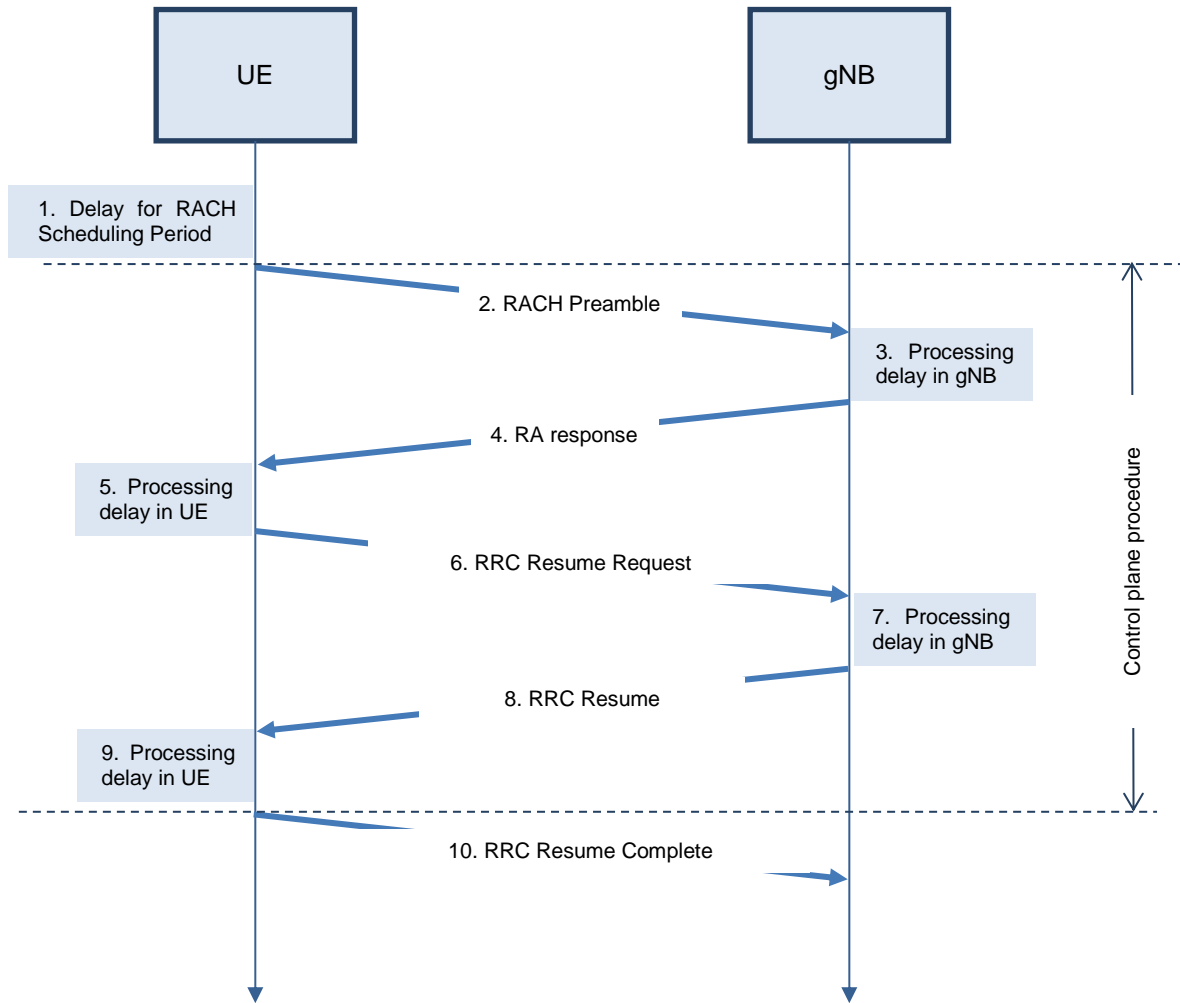
The minimum requirement for control plane latency is 20 ms. Proponents are encouraged to consider lower control plane latency, e.g. 10 ms.

II.5.8.1 Basic parameters – NR Rel-15, control plane latency

For NR Rel-15, control plane latency is evaluated from RRC_INACTIVE state to RRC_CONNECTED state. An example control plane flow for NR Rel-15 is given below (Figure 3).

FIGURE 3

C-plane procedure (Figure 5.7.2.1-1 in TR 37.910, [14])



The detailed assumptions of each step are provided in Table 5.7.2.1-1 of TR 37.910 [14] and is rewritten below (Table 108) for convenience. The evaluation is for UL data transfer. It is understood that the evaluation results for DL data transfer can be further reduced because UE processing delay in Step 9 for DL data transfer does not need to handle UL grant receiving, and therefore can be reduced compared to the case of UL data transfer.

TABLE 108

Assumption of C-plane procedure for NR

Step	Description	CP Latency for UL data transfer [ms]
1	Delay due to RACH scheduling period (1TTI)	0
2	Transmission of RACH Preamble	Length of the preamble according to the PRACH format as specified in [10]
3	Preamble detection and processing in gNB	$T_{proc,2}$ (assuming $d_{2,1}=0$)
4	Transmission of RA response	T_s (the length of 1 slot / non-slot) NOTE: The length of 1 slot or 1 non-slot include PDCCH and PDSCH (the first OFDM symbol of PDSCH is frequency

Step	Description	CP Latency for UL data transfer [ms]
		multiplexed with PDCCH).
5	UE Processing Delay (decoding of scheduling grant, timing alignment and C-RNTI assignment + L1 encoding of RRC Resume Request)	$N_{T,1}+N_{T,2}+0.5$ ms
6	Transmission of RRC Resume Request	T_s (the length of 1 slot / non-slot) NOTE: The length of 1 slot or 1 non-slot is equal to PUSCH allocation length.
7	Processing delay in gNB (L2 and RRC)	3
8	Transmission of RRC Resume	T_s (the length of 1 slot / non-slot)
9	Processing delay in UE of RRC Resume including grant reception	7
10	Transmission of RRC Resume Complete and UP data	0
<p>Notes:</p> <ol style="list-style-type: none"> For step 1, the procedure for <i>transition from a most "battery efficient" state</i> has yet not begun, hence this step is not relevant for the latency of the procedure which is illustrated by a '0' in the above. For step 3, the value of $T_{proc,2}$ is used only for evaluation. gNB processing delay may vary depending on implementation. For step 5, the latency of $N_{T,1}+N_{T,2}+0.5$ms is used according to Section 8.3 of TS 38.213. $N_{T,1}$ is a time duration of N_1 symbols corresponding to a PDSCH reception time for PDSCH processing capability 1 when additional PDSCH DM-RS is configured; and $N_{T,2}$ is a time duration of N_2 symbols corresponding to a PUSCH preparation time for PUSCH processing capability 1. The value of N_1 and N_2 are shown in Table 5.3-1 and Table 6.4-1 of TS38.214, respectively. For step 7, the processing delay in gNB (L2 and RRC) has been reduced to 3 ms. The delays due to inside-gNB or inter-gNB communication are not included in Step 7. Such delays may exist depending on deployment, but are not within the scope of this evaluation. For step 9 for UL data transfer, the processing delay in the UE (L2 and RRC) is considered, i.e., from reception of RRC Connection Resume to the reception of UL grant. The transmission of UL grant by gNB and processing delay in the UE (processing of UL grant and preparing for UL tx) are also considered. The RRCConnectionResume message only includes MAC and PHY configuration. No DRX, SPS, CA, or MIMO re-configuration will be triggered by this message. Further, the UL grant for transmission of RRC Connection Resume Complete and the data is transmitted over common search space with DCI format 0. For step 10, the beginning of this subframe is considered to be "<i>the start of continuous data transfer</i>", hence this step is not relevant for the latency of the procedure which is illustrated by a '0' in the above. For the case of a TDD band (30 kHz SCS) with an SUL band (15 kHz SCS), the sub-carrier spacing of 15 kHz that results in larger delay is used in evaluating the latency for Step 3 and 5. 		

II.5.8.2 Evaluation methodology

According to the methodology that was applied to evaluate CP latency, for each step of the C-plane procedure the corresponding time delays were calculated using the parameters mentioned in Table 108.

Especially for step 3, UE PUSCH preparation procedure time is calculated by means of N_2 symbols duration given in Table 87 for UE Capability 1 and Table 88 for UE Capability 2. Step 5 delay is calculated by means of N_2 symbols duration and PDSCH decoding time N_1 symbols duration given in Table 85 for UE Capability 1 and Table 86 for UE Capability 2.

Moreover, processing time $T_{proc,2}$ of step 3 is calculated by means of equation (3).

Furthermore, in Steps 4 and 6, waiting times are introduced due to starting symbols constraints at downlink and uplink respectively. Specifically, starting symbols constraints for PDSCH are given in Table 90 and for PUSCH in Table 89.

For mapping type A the downlink transmission can start at OFDM symbol 0, 1 or 2 (and 3 if dmrs-TypeA-Position=3) in the slot. In the calculations only S = 0, 1 or 2 was considered for Type A PDSCH. For mapping type B the transmission can start at any of the first 12 OFDM symbols (i.e. it cannot start at the last symbol) in the slot. For both mapping type A and B, the whole transmission must fit inside a slot (i.e. it cannot cross the slot boundary).

For mapping type A the uplink transmission always starts with OFDM symbol 0 in the slot, while the transmission can start at any OFDM symbol for mapping type B. For both mapping type A and B, the whole transmission must fit inside a slot (i.e. it cannot cross the slot boundary).

II.5.8.3 5G NR control plane latency calculations

Based on the above information, our calculations in each step of the procedure are shown in Table 109.

TABLE 109
Control Plane Latency calculation

Step	Latency contribution
1	0 ms
2	$\frac{PRACH\ length}{14} \cdot 2^{-\mu}$
3	T _{proc,2} from the equation on page 35
4	Delay due to mapping type constraints + $\frac{PRACH\ length}{14} \cdot 2^{-\mu}$
5	0.5ms + (N ₁ + N ₂) · $\frac{2^{-\mu}}{14}$, with N ₁ , N ₂ taken from Tables 2,3,4,5
6	Delay due to mapping type constraints + $\frac{PRACH\ length}{14} \cdot 2^{-\mu}$
7	3 ms
8	Delay due to mapping type constraints + $\frac{PRACH\ length}{14} \cdot 2^{-\mu}$
9	7 ms
10	0 ms

The delays due to mapping type constraints are the delays that must be added in order to satisfy the constraints given in Table 89 and Table 90.

For Step 1 the delay due to RACH scheduling period is not included. However, it should be noted that since the start time for the transition from a most "battery efficient state" is not defined in the ITU-R M.2410 document [1], it is not clear if the delay due to RACH scheduling period should be included in the calculation of the Control Plane latency or not. We have chosen to assume that the transition starts with the transmission of the RACH preamble from the UE, hence the delay due to RACH scheduling period is not included.

For step 7 the gNB processing delay is not specified in the 3GPP standard and depends on implementation. We assume that this delay will be 3 ms or less based on experience from LTE-Advanced.

II.5.8.3.1 5G NR FDD

In TR 37.910 [14] based on the control plane procedure and assumptions given in Table 108, a variety of configurations and UE capabilities are evaluated for NR for UL data transfer. For a specific configuration, the results are the average over the possible start timing of the control plane procedure. For NR FDD, the 3GPP evaluation results of different PRACH lengths are provided in Table 5.7.2.1-2 (TR 37.910 [14]). The evaluation is applied to various non-slot length and sub-carrier spacings.

For the same configurations, 5G PPP IMT2020 Evaluation Group calculated Control Plane Latency according to the methodology described above and the results are given below in Table 110.

TABLE 110

Control plane latency (ms) for NR FDD

(a) PRACH length = 2 OFDM symbols

Resource mapping type	Non-slot duration	UE capability 1				UE capability 2		
		15 kHz SCS	30 kHz SCS	60 kHz SCS	120 kHz SCS	15 kHz SCS	30 kHz SCS	60 kHz SCS
Type A	$M=4$ (4OS non-slot)	15.3	12.6	12.3	11.7	15.3	12.6	12.1
	$M=7$ (7OS non-slot)	15.5	13.2	12.4	11.7	15.5	13.2	12.1
Type B	$M=2$ (2OS non-slot)	13.1	12.0	11.8	11.4	12.7	11.8	11.6
	$M=4$ (4OS non-slot)	13.6	12.3	11.9	11.4	13.3	12.0	11.7
	$M=7$ (7OS non-slot)	14.5	12.8	12.1	11.6	14.0	12.8	11.9

(b) PRACH length = 6 OFDM symbols

Resource mapping type	Non-slot duration	UE capability 1				UE capability 2		
		15 kHz SCS	30 kHz SCS	60 kHz SCS	120 kHz SCS	15 kHz SCS	30 kHz SCS	60 kHz SCS
Type A	$M=4$ (4OS non-slot)	15.3	13.1	12.3	11.7	15.3	12.6	12.3
	$M=7$ (7OS non-slot)	15.5	13.8	12.4	11.7	15.5	13.2	12.4
Type B	$M=2$ (2OS non-slot)	13.4	12.1	11.8	11.4	13.0	11.9	11.6
	$M=4$ (4OS non-slot)	13.8	12.4	11.9	11.5	13.6	12.3	11.7
	$M=7$ (7OS non-slot)	14.5	12.8	12.1	11.6	14.5	12.8	12.0

(c) PRACH length=1ms

Resource mapping type	Non-slot duration	UE capability 1		UE capability 2	
		15 kHz SCS	30 kHz SCS	15 kHz SCS	30 kHz SCS
Type A	$M=4$ (4OS non-slot)	16.3	13.6	16.3	13.6
	$M=7$ (7OS non-slot)	16.5	14.2	16.5	14.2
	$M=14$ (14OS slot)	17.0	14.5	17.0	14.5
Type B	$M=2$ (2OS non-slot)	13.9	12.9	13.6	12.7
	$M=4$ (4OS non-slot)	14.6	13.3	14.0	12.9
	$M=7$ (7OS non-slot)	15.5	13.8	15.0	13.2

II.5.8.3.1 5G NR TDD

For NR TDD, various DL/UL configurations are evaluated. The evaluation results of DDDSU (with S slot = 11DL: 1GP:2UL), DSUUD (with S slot = 11DL: 1GP:2UL), and DUDU (without GP) are provided (Table 111, Table 112 and Table 113). The evaluation is applied to various non-slot length and sub-carrier spacings. Resource mapping type A and B are considered. UE capability 1 and UE capability 2 are evaluated.

The calculations were performed using the following assumptions:

- The CP procedure starts with the UE transmitting a RACH pre-amble. The start OFDM symbol can be any symbol where the following constraints are satisfied:
 - All OFDM symbols that the RACH pre-amble spans must be UL OFDM symbols
 - The RACH pre-amble cannot cross a slot boundary

The results below give the control plane latency minimized over the possible start OFDM symbols.

TABLE 111

Control plane latency (ms) for NR TDD
(Frame structure: DDDSU, S slot = 11DL:1GP:2UL)

(a) PRACH length = 2 OFDM symbols

Resource mapping type	Non-slot duration	UE capability 1		UE capability 2	
		15 kHz SCS	30 kHz SCS	15 kHz SCS	30 kHz SCS
Type A	$M=4$ (4OS non-slot)	19.1	14.6	19.1	14.6
	$M=7$ (7OS non-slot)	19.1	14.6	19.1	14.6
Type B	$M=2$ (2OS non-slot)	14.3	12.1	14.3	12.1
	$M=4$ (4OS non-slot)	14.6	12.3	14.6	12.3
	$M=7$	19.1	14.6	19.1	14.6

	(7OS non-slot)				
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(b) PRACH length = 1 ms

Resource mapping type	Non-slot duration	UE capability 1	UE capability 2
		15 kHz SCS	15 kHz SCS
Type A	$M=4$ (4OS non-slot)	20.0	20.0
	$M=7$ (7OS non-slot)	20.0	20.0
Type B	$M=2$ (2OS non-slot)	15.1	15.1
	$M=4$ (4OS non-slot)	15.6	15.6
	$M=7$ (7OS non-slot)	20.0	20.0

TABLE 112

Control plane latency (ms) for NR TDD
(Frame structure: DSUUD, S slot = 11DL:1GP:2UL)

(a) PRACH length = 2 OFDM symbols

Resource mapping type	Non-slot duration	UE capability 1				UE capability 2		
		15 kHz SCS	30 kHz SCS	60 kHz SCS	120 kHz SCS	15 kHz SCS	30 kHz SCS	60 kHz SCS
Type A	$M=4$ (4OS non-slot)	15.1	14.1	12.3	11.9	15.1	14.1	12.3
	$M=7$ (7OS non-slot)	18.1	14.1	13.3	11.9	18.1	14.1	13.3
Type B	$M=2$ (2OS non-slot)	13.3	12.1	12.1	11.7	13.3	12.1	12.1
	$M=4$ (4OS non-slot)	13.6	12.3	12.1	11.7	13.6	12.2	12.1
	$M=7$ (7OS non-slot)	14.4	12.5	12.3	11.8	14.1	12.3	12.3

(b) PRACH length = 6 OFDM symbols

Resource mapping type	Non-slot duration	UE capability 1				UE capability 2		
		15 kHz SCS	30 kHz SCS	60 kHz SCS	120 kHz SCS	15 kHz SCS	30 kHz SCS	60 kHz SCS
Type A	$M=4$ (4OS non-slot)	18.4	14.2	13.4	12.3	18.4	14.2	13.4
	$M=7$ (7OS non-slot)	18.4	14.2	13.4	12.3	18.4	14.2	13.4
Type B	$M=2$ (2OS non-slot)	13.6	12.3	12.1	11.7	13.6	12.3	12.1
	$M=4$ (4OS non-slot)	13.9	12.4	12.2	11.7	13.9	12.4	12.2
	$M=7$ (7OS non-slot)	14.6	12.7	12.4	11.9	14.4	12.5	12.4

(c) PRACH length = 1 ms

Resource mapping type	Non-slot duration	UE capability 1	UE capability 2
		15 kHz SCS	15 kHz SCS
Type A	$M=4$ (4OS non-slot)	19.0	19.0
	$M=7$ (7OS non-slot)	19.0	19.0
Type B	$M=2$ (2OS non-slot)	14.1	14.1
	$M=4$ (4OS non-slot)	14.6	14.6
	$M=7$ (7OS non-slot)	15.5	15.0

TABLE 113

Control plane latency (ms) for NR TDD
(Frame structure: DUDU, without GP)

(a) PRACH length = 2 OFDM symbols

Resource mapping type	Non-slot duration	UE capability 1				UE capability 2		
		15 kHz SCS	30 kHz SCS	60 kHz SCS	120 kHz SCS	15 kHz SCS	30 kHz SCS	60 kHz SCS
Type A	$M=4$ (4OS non-slot)	17.7	12.9	12.3	11.7	17.4	12.7	12.3
	$M=7$ (7OS non-slot)	17.7	13.7	12.3	11.7	17.4	12.7	12.3
Type B	$M=2$ (2OS non-slot)	13.4	12.6	12.	11.6	13.4	12.6	11.8
	$M=4$ (4OS non-slot)	13.7	12.6	12.3	11.6	13.7	12.6	11.8
	$M=7$ (7OS non-slot)	15.4	12.8	12.3	11.7	15.1	12.6	11.9

(b) PRACH length = 6 OFDM symbols

Resource mapping type	Non-slot duration	UE capability 1				UE capability 2		
		15 kHz SCS	30 kHz SCS	60 kHz SCS	120 kHz SCS	15 kHz SCS	30k Hz SCS	60 kHz SCS
Type A	$M=4$ (4OS non-slot)	18.0	13.7	12.4	11.7	17.6	12.9	12.4
	$M=7$ (7OS non-slot)	18.0	13.7	12.4	11.7	17.6	12.9	12.4
Type B	$M=2$ (2OS non-slot)	13.7	12.7	12.4	11.7	13.7	12.7	11.9
	$M=4$ (4OS non-slot)	14.0	12.8	12.4	11.7	14.0	12.7	11.9
	$M=7$ (7OS non-slot)	16.0	12.9	12.4	11.7	15.4	12.7	12.4

(c) PRACH length=1ms

Resource mapping type	Non-slot duration	UE capability 1	UE capability 2
		15 kHz SCS	15 kHz SCS
Type A	$M=4$ (4OS non-slot)	20.0	20.0
	$M=7$ (7OS non-slot)	20.0	20.0
Type B	$M=2$ (2OS non-slot)	14.3	14.3
	$M=4$ (4OS non-slot)	14.6	14.6
	$M=7$ (7OS non-slot)	18.0	16.0

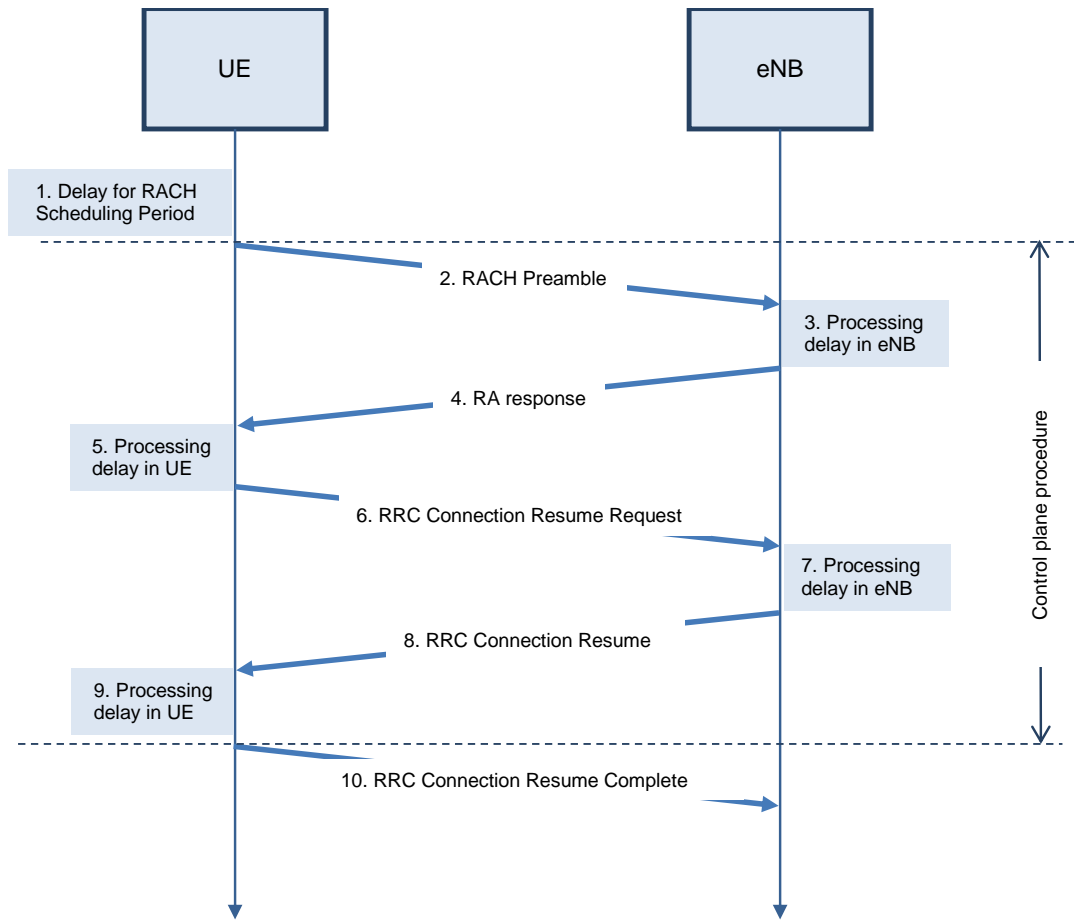
The calculated control plane latencies given in Table 111, Table 112 and Table 113 are all below or equal to the ITU IMT2020 requirement of 20 ms.

II.5.8.4 LTE Rel-15 control plane latency calculations

For LTE Rel-15, control plane latency is evaluated from RRC_IDLE state to RRC_CONNECTED state. The control plane flow for LTE Rel-15 is in Figure 4.

FIGURE 4

Control plane procedure



II.5.8.4.1 LTE FDD

The detailed assumptions of each step are provided in Table 5.7.2.2-1 of TR 37.910 [14] and is rewritten below (Table 114) for convenience. The evaluation is for UL data transfer. It is understood that the evaluation results for DL data transfer can be further reduced because UE processing delay in Step 9 for DL data transfer does not need to handle UL grant receiving, and therefore can be reduced compared to the case of UL data transfer.

TABLE 114

Control plane latency for LTE FDD

Step	Description	CP Latency for UL data transfer [ms]
1	Delay due to RACH scheduling period (ITTI)	0
2	Transmission of RACH Preamble	1
3	Preamble detection and processing in eNB	2
4	Transmission of RA response	1

Step	Description	CP Latency for UL data transfer [ms]
5	UE Processing Delay (decoding of scheduling grant, timing alignment and C-RNTI assignment + L1 encoding of RRC Connection Resume Request)	4
6	Transmission of RRC Connection Resume Request	1
7	Processing delay in eNB (L2 and RRC)	3
8	Transmission of RRC Connection Resume	1
9	Processing delay in UE of RRC Connection Resume including grant reception	7
10	Transmission of RRC Connection Resume Complete and UP data	0
	Total delay [ms]	20

Notes:

- For step 1, the procedure for *transition from a most "battery efficient" state* has yet not begun, hence this step is not relevant for the latency of the procedure which is illustrated by a '0' in the above.
- For step 5, the latency of 4 ms has been agreed by RAN1, see LS in R2-1806411.
- For step 7, the processing delay in eNB (L2 and RRC) has been reduced to 3 ms.
- For step 9 for UL data transfer, the processing delay in the UE (L2 and RRC) is considered, i.e., from reception of RRC Connection Resume to the reception of UL grant. The transmission of UL grant by eNB and processing delay in the UE (processing of UL grant and preparing for UL tx) are also considered. The RRCConnectionResume message only includes MAC and PHY configuration. No DRX, SPS, CA, or MIMO re-configuration will be triggered by this message. Further, the UL grant for transmission of RRC Connection Resume Complete and the data is transmitted over common search space with DCI format 0.
- For step 9 for DL data transfer, only the processing delay in the UE (L2 and RRC) is considered, i.e., from reception of RRC Connection Resume to the reception of DL grant. The RRCConnectionResume message only includes MAC and PHY configuration. No DRX, SPS, CA, or MIMO re-configuration will be triggered by this message. Further, the UL grant for transmission of RRC Connection Resume Complete and the data is transmitted over common search space with DCI format 0.
- For step 10, the beginning of this subframe is considered to be "*the start of continuous data transfer*", hence this step is not relevant for the latency of the procedure which is illustrated by a '0' in the above.

Based on the above analysis, the 20 ms control plane latency requirement is fulfilled by LTE Rel-15 FDD.

II.5.8.4.2 LTE TDD

There are seven uplink-downlink configurations defined for LTE as listed in Table 115.

TABLE 115
Uplink-downlink configurations for LTE TDD (from TS 36.211)

Uplink-downlink configuration	Downlink-to-Uplink Switch-point periodicity	Subframe number									
		0	1	2	3	4	5	6	7	8	9
0	5 ms	D	S	U	U	U	D	S	U	U	U
1	5 ms	D	S	U	U	D	D	S	U	U	D
2	5 ms	D	S	U	D	D	D	S	U	D	D
3	10 ms	D	S	U	U	U	D	D	D	D	D
4	10 ms	D	S	U	U	D	D	D	D	D	D
5	10 ms	D	S	U	D	D	D	D	D	D	D
6	5 ms	D	S	U	U	U	D	S	U	U	D

The control plane latency was calculated based on the following assumptions:

- The UE can send the PRACH preamble in a Special (S) slot or in an Uplink (U) slot. In the former case the start of the preamble is $4832 \cdot T_s$ before end of UpPTS (as specified in TS 36.211)
- The UE can send control messages in any Uplink (U) slot
- The eNB can send downlink control messages in any S-slot and any Downlink (D) slot.

The minimum control plane latencies that can be achieved for downlink data transfer are given in Table 116 for the different uplink-downlink TDD configurations.

TABLE 116

Control plane latency for downlink data transfer

	Config 0	Config 1	Config 2	Config 3	Config 4	Config 5	Config 6
CP latency	17 ms	17 ms	18 ms	16 ms	17 ms	18 ms	17 ms

The minimum control plane latencies that can be achieved for uplink data transfer are given in Table 117 for the different uplink-downlink TDD configurations.

TABLE 117

Control plane latency for uplink data transfer

	Config 0	Config 1	Config 2	Config 3	Config 4	Config 5	Config 6
CP latency	21 ms	21 ms	22 ms	20 ms	21 ms	22 ms	20.2 ms

Based on the above analysis, the 20ms control plane latency requirement is fulfilled for all uplink-downlink TDD configurations for downlink data transfer, and for one of the uplink-downlink TDD configuration for uplink data transfer.

II.5.8.5 Conclusions

The 5G PPP evaluation results given in Table 110 are quite close to the values provided by 3GPP for 5G NR FDD. The calculated control plane latencies were below the ITU IMT2020 requirement of 20 ms in all cases. The minimum latency value is approaching 11 ms for configurations with 120 kHz subcarrier spacing. No configuration achieved a control plane latency below 10 ms.

For 5G NR TDD the calculated control plane latencies given in Table 111, Table 112 and Table 113 were below or equal to the ITU IMT2020 requirement of 20 ms in all cases.

For LTE Rel-15 FDD the calculations in Table 114 show that the control plane latency is equal to 20 ms, which is the same as ITU's requirement. For LTE Rel-15 TDD the maximum control plane latency requirement of 20 ms is satisfied for all uplink-downlink TDD configurations for downlink data transfer as shown in Table 116, and for one TDD configurations for uplink data transfer as shown in Table 117.

II.5.9 Connection density

The ITU-R minimum requirements on connection density are given in [1]. The following requirements and remarks are extracted from [1]:

Connection density is the total number of devices fulfilling a specific quality of service (QoS) per unit area (per km²).

Connection density should be achieved for a limited bandwidth and number of TRxPs. The target QoS is to support delivery of a message of a certain size within a certain time and with a certain success probability, as specified in Report ITU-R M.2412-0.

This requirement is defined for the purpose of evaluation in the mMTC usage scenario.

The minimum requirement for connection density is 1 000 000 devices per km².

The evaluation methodology is described in [3], Section 7.1.3 and in Section III-9.1. In this report, mainly NR evaluation takes place due to the fact that connection density is one of the main challenges that NR tries to solve compared to previous releases.

Based on the reasoning given at the beginning of Section II.5.3 only 5G-NR RIT is evaluated.

II.5.9.1 Evaluation methodology and KPIs

In mMTC environments, one of the important parameters is the connection density of devices. According to ITU document [1] the connection density is the total number of devices fulfilling a specific quality of service (QoS) per unit area (per km²). Connection density should be achieved for a limited bandwidth and number of connectivity points. The target QoS is to support delivery of a message of a certain size within a certain time and with a certain success probability. This requirement is defined for the purpose of evaluation in the mMTC usage scenario. According to ITU, the minimum requirement for connection density is 1 000 000 devices per km².

Also, ITU has defined the following steps, for the evaluation of connection density [3]:

- Step 1: Set system user number per TRxP as N.
- Step 2: Generate the user packet according to the traffic model.
- Step 3: Run non-full buffer system-level simulation to obtain the packet outage rate. The outage rate is defined as the ratio of the number of packets that failed to be delivered to the destination receiver within a transmission delay of less than or equal to 10s to the total number of packets generated in Step 2.
- Step 4: Change the value of N and repeat Step 2-3 to obtain the system user number per TRxP N' satisfying the packet outage rate of 1%.
- Step 5: Calculate connection density by equation $C = N' / A$, where the TRxP area A is calculated as $A = \text{ISD}^2 \times \sqrt{3}/6$, and ISD is the inter-site distance.
- The requirement is fulfilled if the connection density C is greater than or equal to 1 000 000. The simulation bandwidth used to fulfil the requirement should be reported. Additionally, it is encouraged to report the connection efficiency (measured as N' divided by simulation bandwidth) for the achieved connection density.

The considered traffic model for such an evaluation is message size of 32 bytes with either 1 message/day/device or 1 message/2 hours/device. Packet arrival follows Poisson arrival process for non-full buffer system-level simulation.

II.5.9.2 Simulation results

System-level simulations have been conducted for the evaluation of connection density in mMTC environments. Narrowband parameters are taken into account in the simulation. As such, considered bandwidth is from 180 kHz up to 1.08 MHz. The success rate (i.e. successful transmission of messages) is calculated in order to check the acceptable level of connection density for meeting the threshold of 99% of success (1% of loss). During the evaluation process, the lower number of the considered message generation frequency (e.g. 1 message/day/device) fulfils the requirements of the connection density. The results showed that the 99th percentile of the delay per user was less than 10s for both the 180 kHz and 1.08 MHz tests. Two configurations for ISD (Inter Site Distance) of 500 m and 1 732 m were examined during the evaluation. As a result, the focus was given on the investigation and analysis of the higher message frequency of 1 message/2 hours/device which had a different behavior than the previous.

Figure 5 shows the success rate for different number of devices when bandwidth of 180 kHz is used. According to the results, it is evident that with such bandwidth, up to 2 million devices per km² assuming messages of 32 bytes and 1 message/2 hours/device can be served. When 3 million devices per km² were simulated, the success rate dropped below 99%.

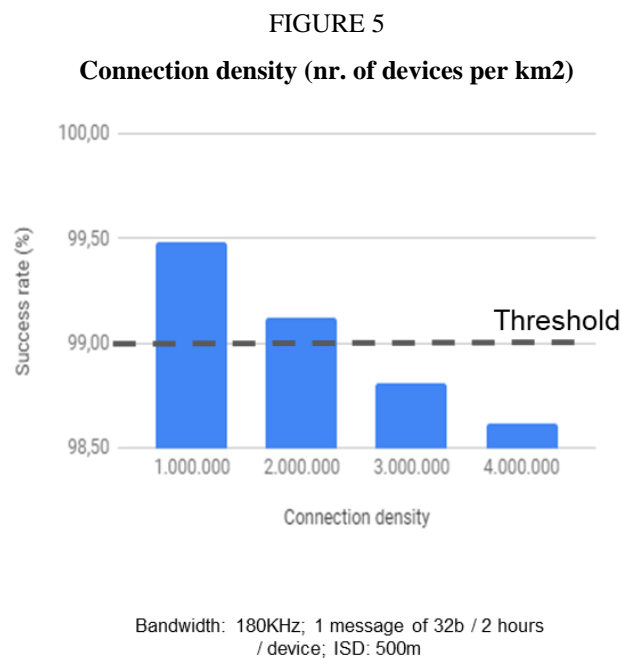
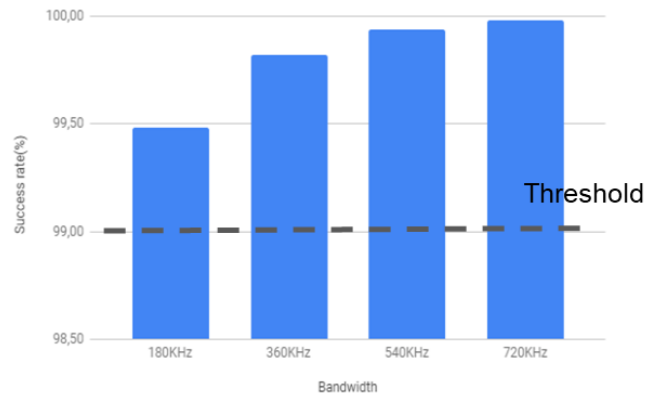


Figure 6 shows how much bandwidth is needed for serving 1 million devices with 1 message of 32 bytes/2 hours/device as we have seen at Figure 5, but this time by examining at which level the success rate will reach the highest level. The results show that even from 180 kHz, the success rate of 99% is fulfilled and as the bandwidth increases, the success rate is even higher, reaching almost the 100% at 540 kHz.

FIGURE 6

Success rate depending on bandwidth (ISD 500m)

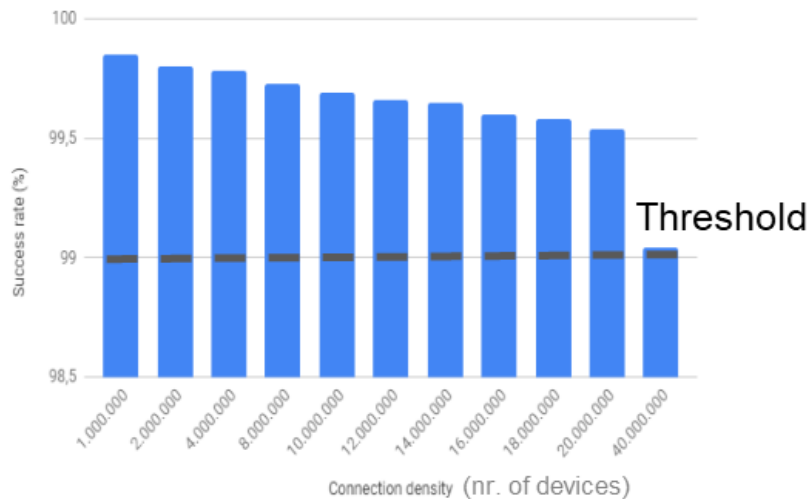


Devices: 1,000,000; 1 message of 32b / 2 hours / device; ISD: 500m

As a next step we changed the simulation parameters to higher ISD value of 1 732 m and run the same evaluation process as before. Figure 7 shows the success rate for different number of devices when bandwidth of 1.08 MHz is used. According to the results, it is evident that with such bandwidth, up to 40 million devices per km² can be enabled in the area without serious problems assuming messages of 32 bytes and 1 message/2 hours/device.

FIGURE 7

Connection density (nr. of devices per km2)

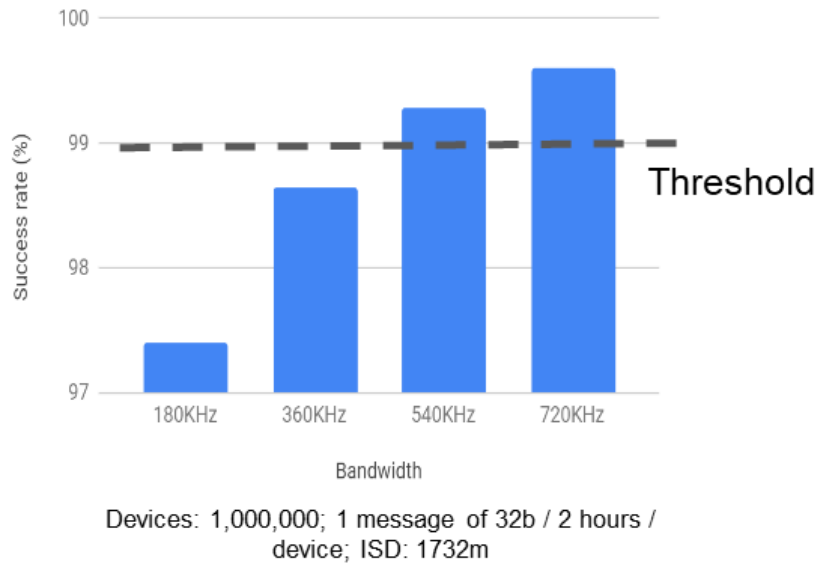


Bandwidth: 1.08MHz; 1 message of 32b / 2 hours / device; ISD: 1732m

Figure 8 shows how much bandwidth is needed for serving 1 million devices with 1 message of 32 bytes/2 hours/device. The results show that from 500 kHz and above, the success rate of 99% is met. However, smaller bandwidths (e.g. 180 or 360 kHz) are possible but the success rate is a bit lower than 99%.

FIGURE 8

Success rate depending on bandwidth (ISD 1732m)



II.5.9.3 Summary

Connection density is an important metric in mMTC environments. Also, the usage of narrowband technologies is encouraged, especially for small and frequent transmissions. As a result, the provided evaluations take into account these assumptions in order to show the number of devices that can be supported with a specific QoS. In cases of 180 kHz of bandwidth the scenarios of ISD at 500 m showed that there were not any major problems for the device density that was considered. In addition, the results for ISD of 1 732 m reveal that there is a need of higher bandwidths to meet the requirements and achieve the proposed success rates, which in many cases more than three times the initial bandwidth had to be used. Also, the results are consistent with the results of vendors in 3GPP [14] who followed the same evaluation process, utilizing the same parameters at their proprietary simulator. For the bandwidth of 1.08 MHz the evaluation process showed that it is possible to handle effectively more than 1 million devices per km² in every situation.

It can be noted that 1 million devices is the minimum requirement of ITU-R for connection density evaluation.

II.5.10 Energy efficiency

The ITU-R minimum requirements on energy efficiency are given in [1]. The following requirements and remarks are extracted from [1]:

Network energy efficiency is the capability of a RIT/SRIT to minimize the radio access network energy consumption in relation to the traffic capacity provided.

Device energy efficiency is the capability of the RIT/SRIT to minimize the power consumed by the device modem in relation to the traffic characteristics.

Energy efficiency of the network and the device can relate to the support for the following two aspects:

- a) *Efficient data transmission in a loaded case;*
- b) *Low energy consumption when there is no data.*

Efficient data transmission in a loaded case is demonstrated by the average spectral efficiency (see § 4.5, also look at Section III-5 of this report).

Low energy consumption when there is no data can be estimated by the sleep ratio. The sleep ratio is the fraction of unoccupied time resources (for the network) or sleeping time (for the device) in a period of time corresponding to the cycle of the control signaling (for the network) or the cycle of discontinuous reception (for the device) when no user data transfer takes place. Furthermore, the sleep duration, i.e. the continuous period of time with no transmission (for network and device) and reception (for the device), should be sufficiently long.

This requirement is defined for the purpose of evaluation in the eMBB usage scenario.

The RIT/SRIT shall have the capability to support a high sleep ratio and long sleep duration. Proponents are encouraged to describe other mechanisms of the RIT/SRIT that improve the support of energy efficient operation for both network and device.

Guidelines for the evaluation methodology is given in [3] (M.2412). The following is extracted from [3]:

The energy efficiency for both network and device is verified by inspection by demonstrating that the candidate RITs/SRITs can support high sleep ratio and long sleep duration as defined in Report ITU-R M.2410-0 when there is no data.

Inspection can also be used to describe other mechanisms of the candidate RITs/SRITs that improve energy efficient operation for both network and device.

Hence, only the energy efficiency in the unloaded case is evaluated in this section. The energy efficiency in the loaded case is evaluated in Section II-5 of this report.

II.5.10.1 Different technical concepts to improve energy efficiency in the system description as submitted by 3GPP

According to [1] and [3] there are no quantitative requirements on energy efficiency. Therefore, only a qualitative evaluation of different proposed technical concepts for the improvement of energy efficiency can be evaluated.

II.5.10.1.1 NR RIT of “5G” [8], Section 5.2.3.2.25

Network energy efficiency

The fundamental always-on transmission that must take place is the periodic SS/PBCH block. The SS/PBCH block is used for the UE to detect the cell, obtain basic information of it on PBCH, and maintain synchronization to it. The duration, number and frequency of the SS/PBCH block transmission depends on the network setup. For the purposes of blind initial access the UE may assume that there is an SS/PBCH block once every 20 ms. If the network is configured to transmit the SS/PBCH block less frequently, that will improve the network energy efficiency at the cost of increased initial cell detection time. But after the initial connection has been established, the UE may be informed of the configured SS/PBCH block periodicity in the cell from the set of {5, 10, 20, 40, 80, 160} ms. If the cell set up uses analogue beamformer component, it may provide several SS/PBCH blocks multiplexed in time-domain fashion within one SS/PBCH block period.

Remaining minimum system information carried over SIB1 needs to be broadcast at least in the cells in which the UEs are expected to be able to set up the connection to the network.

There is no specific rate at which the SIB1 needs to be repeated in the cell, and once the UE acquires the SIB1, it does not need to read it again. SIB1 could be time or frequency multiplexed with the SS/PBCH block. In the frequency multiplexing case, there would be no additional on-time for the gNB transmitter. In the time multiplexing case, having a lower rate for SIB1 than for SS/PBCH block would suffice at least for higher SS/PBCH repetition frequencies.

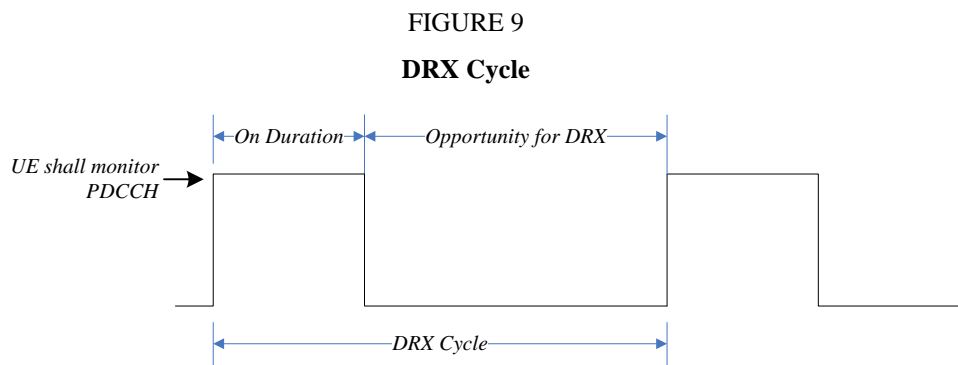
The sleep ratio under the above mechanism is evaluated in [14].

Device energy efficiency

Multiple features facilitating device energy efficiency have been specified for NR Rel-15.

Discontinuous reception (DRX) in RRC_CONNECTED, RRC_INACTIVE and RRC_IDLE. When DRX is configured, the UE does not have to continuously monitor PDCCH for scheduling or paging messages, but it can remain sleeping. DRX is characterized by the following:

- **on-duration:** duration that the UE waits for, after waking up, to receive PDCCHs. If the UE successfully decodes a PDCCH, the UE stays awake and starts the inactivity timer;
- **inactivity-timer:** duration that the UE waits to successfully decode a PDCCH, from the last successful decoding of a PDCCH, failing which it can go back to sleep. The UE shall restart the inactivity timer following a single successful decoding of a PDCCH for a first transmission only (i.e. not for retransmissions);
- **retransmission-timer:** duration until a retransmission can be expected;
- **DRX cycle:** specifies the periodic repetition of the on-duration followed by a possible period of inactivity (see Figure 9).



Bandwidth part (BWP) adaptation

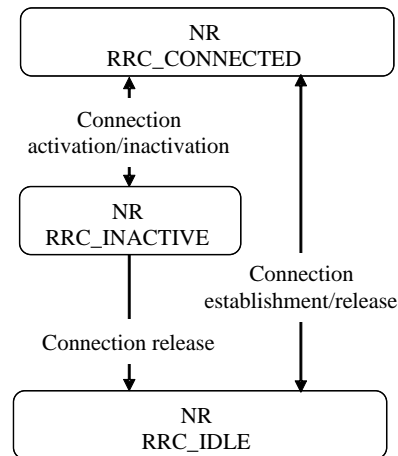
With dynamic bandwidth part adaptation, the UE can fall-back to monitoring the downlink and transmitting the uplink over a narrower bandwidth than the nominal carrier bandwidth used for high data rate transactions. This allows the UEs BB-RF interface to operate with a much lower clock rate and thus reduce energy consumption. Lower data rate exchange can still take place so that there is no need to resume full bandwidth operation just for exchanging network signalling messages or always-on packets of applications. The UE can be moved to the narrow BWP by gNBs transmitting a BWP switch bit on the scheduling DCI on the PDCCH or based on an inactivity timer. UE can be moved back to the full bandwidth operation at any time by the gNB with the BWP switch bit.

RRC_INACTIVE state

The introduction of RRC-inactive state to the RRC state machine (Figure 10) allows for the UE to maintain RRC connection in an inactive state while having the battery saving characteristics of the Idle mode. This allows for maintaining the RRC connection also when the UE is inactive for longer time durations and avoid the signaling overhead and related energy consumption needed when the RRC connection is re-established from Idle mode.

FIGURE 10

NR RRC state machine



Pipelining frame structure enabling micro-sleep within slots in which the UE is not scheduled

The fact that the typical data transmission employs a control channel in the beginning of the slot, and the absence of the continuous reference signal to receive for channel estimate maintenance allows for the UE to determine early on in the slot whether there is a transmission to it, and if there is no data for it to decode, it may turn off its receiver until the end of the slot.

Additional power saving mechanisms for NR are under study for 3GPP Release 16.

II.5.10.1.2 SRIT of “5G” [8], Section 5.2.3.2.25

For NR component RIT

Network energy efficiency

The fundamental always-on transmission that must take place is the periodic SS/PBCH block. The SS/PBCH block is used for the UE to detect the cell, obtain basic information of it on PBCH, and maintain synchronization to it. The duration, number and frequency of the SS/PBCH block transmission depends on the network setup. For the purposes of blind initial access the UE may assume that there is an SS/PBCH block once every 20 ms. If the network is configured to transmit the SS/PBCH block less frequently, that will improve the network energy efficiency at the cost of increased the initial cell detection time, but after the initial connection has been established, the UE may be informed of the configured SS/PBCH block periodicity in the cell from set of {5, 10, 20, 40, 80, 160} ms. If the cell set up uses analogue beamformer component, it may provide several SS/PBCH blocks multiplexed in time-domain fashion within one SS/PBCH block period.

Remaining minimum system information carried over SIB1 needs to be broadcast at least in the cells in which the UEs are expected to be able to set up the connection to the network. There is no specific rate at which the SIB1 needs to be repeated in the cell, and once the UE acquires the SIB1, it does not need to read it again. SIB1 could be time or frequency multiplexed with the SS/PBCH block. In the frequency multiplexing case, there would be no additional on-time for the gNB transmitter. In the time multiplexing case, having a lower rate for SIB1 than for SS/PBCH block would suffice at least for higher SS/PBCH repetition frequencies.

The sleep ratio under the above mechanism is evaluated in [14].

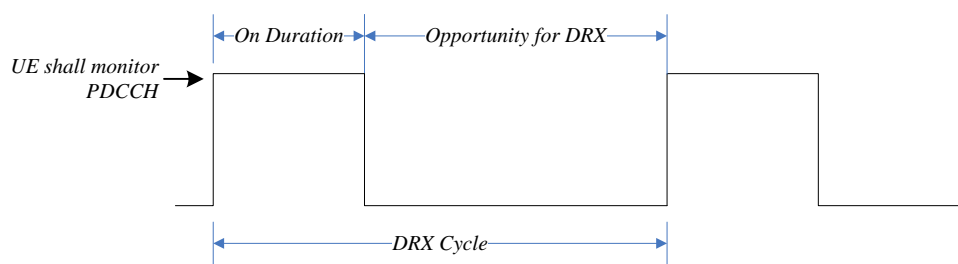
Device energy efficiency

Multiple features facilitating device energy efficiency have been specified for NR Rel-15.

Discontinuous reception (DRX) in RRC_CONNECTED, RRC_INACTIVE and RRC_IDLE. When DRX is configured, the UE does not have to continuously monitor PDCCH for scheduling or paging messages, but it can remain sleeping. DRX is characterized by the following:

- **on-duration:** duration that the UE waits for, after waking up, to receive PDCCHs. If the UE successfully decodes a PDCCH, the UE stays awake and starts the inactivity timer;
- **inactivity-timer:** duration that the UE waits to successfully decode a PDCCH, from the last successful decoding of a PDCCH, failing which it can go back to sleep. The UE shall restart the inactivity timer following a single successful decoding of a PDCCH for a first transmission only (i.e. not for retransmissions);
- **retransmission-timer:** duration until a retransmission can be expected;
- **DRX cycle:** specifies the periodic repetition of the on-duration followed by a possible period of inactivity (see Figure 11).

FIGURE 11
DRX Cycle



Bandwidth part (BWP) adaptation

With dynamic bandwidth part adaptation, the UE can fallback to monitoring the downlink and transmitting the uplink over a narrower bandwidth than the nominal carrier bandwidth used for high data rate transactions. This allows the UEs BB-RF interface to operate with a much lower clock rate and thus reduce energy consumption. Lower data rate exchange can still take place so that there is no need to resume full bandwidth operation just for exchanging network signaling messages or always-on packets of applications. The UE can be moved to the narrow BWP by gNBs transmitting a BWP switch bit on the scheduling DCI on the

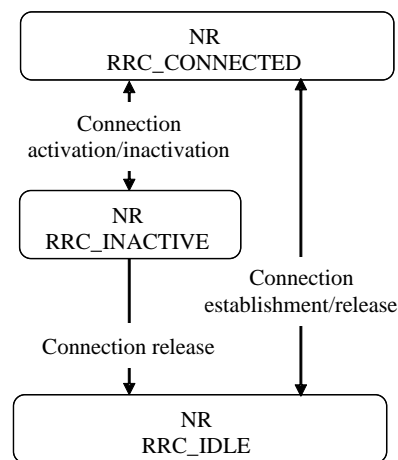
PDCCH or based on an inactivity timer. UE can be moved back to the full bandwidth operation at any time by the gNB with the BWP switch bit.

RRC_INACTIVE state

The introduction of RRC-inactive state to the RRC state machine (Figure 12) allows for the UE to maintain RRC connection in an inactive state while having the battery saving characteristics of the Idle mode. This allows for maintaining the RRC connection also when the UE is inactive for longer time durations and avoid the signaling overhead and related energy consumption needed when the RRC connection is re-established from Idle mode.

FIGURE 12

NR RRC state machine



Pipelining frame structure enabling micro-sleep within slots in which the UE is not scheduled

The fact that the typical data transmission employs a control channel in the beginning of the slot, and the absence of the continuous reference signal to receive for channel estimate maintenance allows for the UE to determine early on in the slot whether there is a transmission to it, and if there is no data for it to decode, it may turn off its receiver until the end of the slot.

Additional power saving mechanisms for NR are under study for 3GPP Release 16.

For LTE component RIT:

Network energy efficiency

In the LTE system the capacity boosting cells can be distinguished from cells providing basic coverage. This can be used to enhance network energy efficiency by switching off LTE or EN-DC cells providing additional capacity when its capacity is not needed and re-activate the cells on a need basis.

The eNB owning a capacity booster cell can autonomously decide to switch-off such a cell to lower energy consumption (dormant state). The decision is typically based on cell load information, consistently with configured information. The switch-off decision may also be taken by O&M. The eNB may initiate handover actions in order to off-load the cell being switched off and may indicate the reason for handover with an appropriate cause value to support the target node in taking subsequent actions, e.g. when selecting the target cell for

subsequent handovers. All peer eNBs are informed by the eNB owning the concerned cell about the switch-off actions over the X2 interface with the eNB Configuration Update procedure. The eNB indicates the switch-off action to a GERAN and/or UTRAN node with the eNB Direct Information Transfer procedure over S1. All informed nodes maintain the cell configuration data, e.g., neighbour relationship configuration, also when a certain cell is dormant. If basic coverage is ensured by E-UTRAN cells, eNBs owning non-capacity boosting cells may request a re-activation over the X2 interface if capacity needs in such cells demand to do so. This is achieved via the Cell Activation procedure. If basic coverage is ensured by UTRAN or GERAN cells, the eNB owning the capacity booster cell may receive a re-activation request from a GERAN or UTRAN node with the MME Direct Information Transfer procedure over S1. The eNB owning the capacity booster cell may also receive from the sending GERAN or UTRAN node the minimum time before that cell switches off; during this time, the same eNB may prevent idle mode UEs from camping on the cell and may prevent incoming handovers to the same cell.

Device energy efficiency

Multiple features facilitating device energy efficiency have been specified for LTE Rel-15.

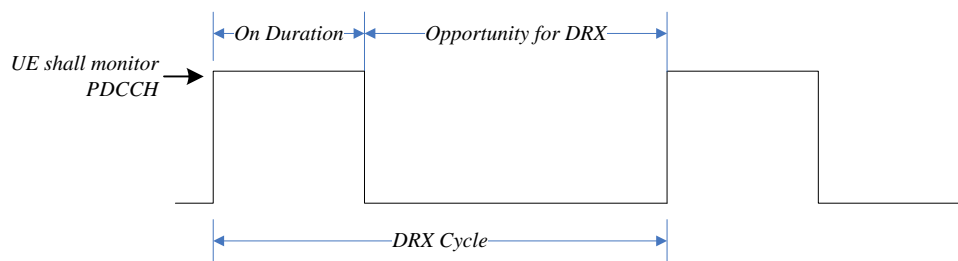
Discontinuous reception (DRX) in RRC connected mode

When DRX is configured, the UE does not have to continuously monitor PDCCH for scheduling or paging messages, but it can remain sleeping. DRX is characterized by the following:

- **on-duration:** duration that the UE waits for, after waking up, to receive PDCCHs. If the UE successfully decodes a PDCCH, the UE stays awake and starts the inactivity timer;
- **inactivity-timer:** duration that the UE waits to successfully decode a PDCCH, from the last successful decoding of a PDCCH, failing which it can go back to sleep. The UE shall restart the inactivity timer following a single successful decoding of a PDCCH for a first transmission only (i.e. not for retransmissions);
- **retransmission-timer:** duration until a retransmission can be expected;
- **DRX cycle:** specifies the periodic repetition of the on-duration followed by a possible period of inactivity (see Figure 13).

FIGURE 13

DRX Cycle



Discontinuous reception (DRX) in RRC idle mode

The UE may use discontinuous reception (DRX) to reduce power consumption in idle mode. When DRX is used, the UE wakes up and listens to PDCCH only on specific paging occasion

defined in-terms of paging frame and subframe within period of N radio frames defined by the DRX cycle of the cell. The UE can remain in sleep mode for remaining duration within DRX cycle.

The UE listens to PDCCH on the paging occasion and decodes the PDCCH based on P-RNTI and if the PDCCH decoding is success, UE decodes the PDSCH indicated in the PDCCH. The UE enters into sleep mode if the PDCCH decoding is not successful or if the UE does not find any page for its UE-ID in the paging message.

The paging occasion of UE within DRX cycle is determined based on the UE-ID, DRX cycle and nB. n is the number of paging occasions per DRX cycle. Higher the value of nB indicates lesser the paging occasions within DRX cycle and vice versa.

For higher sleep ratio, higher DRX cycle needs to be configured at the cell.

Extended discontinuous reception (DRX) in RRC idle mode

To support higher sleep duration upto several hours for low complexity mMTC devices, extended DRX functionality can be configured in LTE.

When eDRX is configured for UE, the UE wakes up periodically in every longer DRX cycle defined as eDRX cycle for short duration called paging window to monitor the PDCCH for reception of paging message. The eDRX cycle length is configured in terms of number of hyper-frames (1 hyper frame =1024 radio frames) by higher layers. Maximum value of eDRX cycle is 256 hyper frames for LTE and 1024 for NB-IoT devices.

During the paging window, the UE monitors the PDCCH using the DRX cycle configured for the cell. The paging window duration will be longer than DRX cycle so that UE monitors for paging message in more than one paging occasion within paging window. (See Figure 14.)

FIGURE 14

Paging window

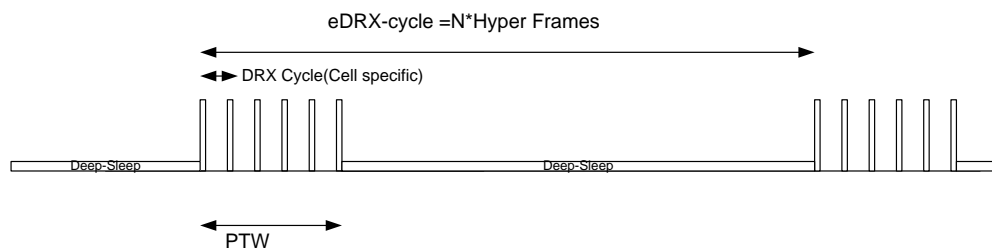


Illustration of Paging reception of UE configured with eDRX

The PTW is UE specific and defined in terms of PH (paging hyper frame) and starting and end position of the paging window within the paging hyper-frame.

The paging hyper frame is selected based on UE-ID and the extended DRX-cycle value. The length of extended DRX-cycle value can be configured as multiples of hyper-frame (1024 radio frames). Maximum eDRX length can be 1024 hyper frames (approximately) 3 hours.

The paging occasions where UE should monitor PDCCH for the UE configured with eDRX is given in terms of paging window within eDRX cycle. The start of paging window is aligned to the paging hyper frame calculated based on eDRX cycle and UE-ID. Within paging hyper frame, the paging window starts at radio frames in multiples of 256. The actual starting radio frame is determined based on UE-ID. From start of paging window UE

monitors all the paging occasions until the end of paging window which is calculated based on paging window length configured by upper layers.

The UE enters into sleep mode at the end of PTW or if it has received a valid page for its UE ID within PTW whichever happens earlier and wakes up only during the next occurrence of PTW in the next eDRX cycle.

Paging with wake-up signal in idle mode

When UE supports WUS and the cell is configured to support WUS transmission, UE shall monitor WUS prior to paging reception on the PO. If DRX is used and if UE detects WUS it reads the PDCCH in the following PO. If eDRX is configured and if the UE detects WUS within its paging window, it monitors N paging occasions configured by higher layers. If the UE does not detect WUS it need not monitor the following paging occasions.

Power saving mode operation in idle mode (PSM)

The UE may be configured by higher layers to enter into indefinite sleep after a configurable timer duration from the last successful uplink transmission. The UE exits the sleep mode when it needs to send the next uplink transmission for sending tracking area update or for application data transmission. The UE is not expected to listen to any downlink channels including PDCCH for paging when it is in sleep mode. Any network-initiated downlink data transmission towards the UE needs to be delayed until UE accesses the network for the next uplink transmission.

For EN-DC operation:

In EN-DC operation, the en-gNB may autonomously decide to switch-off NR cells to lower energy consumption. MeNBs are informed by the en-gNB owning the concerned cell about the switch-off actions over the X2 interface with the EN-DC Configuration Update procedure. The en-gNB may initiate dual connectivity procedures towards the MeNB in order to off-load the cell being switched off and may indicate the reason for release or modification with an appropriate cause value to support the master node in taking subsequent actions. The MeNB may request a re-activation over the X2 interface if capacity needs demand to do so. This is achieved via the EN-DC Cell Activation procedure. The switch-on decision may also be taken by O&M. All peer eNBs are informed by the en-gNB owning the concerned NR cell about the re-activation by an indication on the X2 interface.

II.5.10.2 Evaluation of sleep ratio and sleep duration

II.5.10.2.1 5G NR

II.5.10.2.1.1 NR network side

The sleep ratio for NR on the network side is given in [14], and the following Table 118 and Table 119 for the sleep ratio is taken from there:

TABLE 119

NR network sleep ratio in slot level (from [14])

SSB configuration		SSB set periodicity P_{SSB}					
SCS [kHz]	Number of SS/PBCH block per SSB set, L	5 ms	10 ms	20 ms	40 ms	80 ms	160 ms
15 kHz	1	80.00%	90.00%	95.00%	97.50%	98.75%	99.38%
	2	80.00%	90.00%	95.00%	97.50%	98.75%	99.38%
30 kHz	1	95.00%	97.50%	98.75%	99.38%	99.69%	99.84%
	4	80.00%	90.00%	95.00%	97.50%	98.75%	99.38%
120 kHz	8	90.00%	95.00%	97.50%	98.75%	99.38%	99.69%
	16	80.00%	90.00%	95.00%	97.50%	98.75%	99.38%
240 kHz	16	90.00%	95.00%	97.50%	98.75%	99.38%	99.69%
	32	80.00%	90.00%	95.00%	97.50%	98.75%	99.38%

TABLE 120

NR network sleep ratio in symbol level (from [14])

SSB configuration		SSB set periodicity P_{SSB}					
SCS [kHz]	Number of SS/PBCH block per SSB set, L	5 ms	10 ms	20 ms	40 ms	80 ms	160 ms
15 kHz	1	93.57%	96.43%	97.86%	98.93%	99.46%	99.73%
	2	87.14%	92.86%	95.71%	97.86%	98.93%	99.46%
30 kHz	1	96.79%	98.21%	98.93%	99.46%	99.73%	99.87%
	4	87.14%	92.86%	95.71%	97.86%	98.93%	99.46%
120 kHz	8	94.29%	97.14%	98.57%	99.29%	99.64%	99.82%
	16	88.57%	94.29%	97.14%	98.57%	99.29%	99.64%
240 kHz	16	94.29%	97.14%	98.57%	99.29%	99.64%	99.82%
	32	88.57%	94.29%	97.14%	98.57%	99.29%	99.64%

From Table 118 it can be seen that with SSB set period of 5 ms, more than 80% of sleep ratio can be obtained, and with SSB set period larger than 10 ms more than 90% of sleep ratio can be obtained.

Table 119 shows that the sleep ratio is higher with finer sleep granularity (symbol level).

Therefore, it can be concluded that 5G NR networks can achieve high sleep ratio in the unloaded case.

The sleep duration for NR on the network side is given in [14], and Table 120 for the sleep duration is taken from there.

TABLE 120

NR network sleep duration (ms) in slot level (from [14])

SSB configuration		SSB set periodicity P_{SSB}					
SCS [kHz]	Number of SS/PBCH block per SSB set, L	5 ms	10 ms	20 ms	40 ms	80 ms	160 ms
15 kHz	1	4.00	9.00	19.00	39.00	79.00	159.00
	2	4.00	9.00	19.00	39.00	79.00	159.00
30 kHz	1	4.50	9.50	19.50	39.50	79.50	159.50
	4	4.00	9.00	19.00	39.00	79.00	159.00
120 kHz	8	4.50	9.72	18.92	39.03	78.97	158.99
	16	4.00	9.88	18.77	39.05	78.96	158.99
240 kHz	16	4.50	9.86	18.90	39.04	78.97	158.99
	32	4.00	9.94	18.76	39.06	78.96	158.99

From Table 120 it can be seen that with SSB set period of 160 ms, more than 150 ms sleep duration can be obtained. It can therefore be concluded that NR networks can achieve long sleep duration in unloaded case.

Since NR both support high sleep ratios and long sleep durations, NR meets the energy efficiency requirement in the unloaded case for the network side.

II.5.10.2.1.2 NR device side

The sleep ratio for NR on the device side is given in [14], Table 121 and Table 122 for the sleep ratio is taken from there

TABLE 121

NR device sleep ratio in slot level (for idle / inactive mode)

	Paging cycle $N_{PC,RF} * 10$ (ms)	SCS(kHz)	SSB L	SSB reception time(ms)	SSB cycle (ms)	Number of SSB burst set	RRM measurement time per DRX (ms)	Transition time(ms)	Sleep ratio
RRC-Idle/Inactive	320	240	32	1	–	1	3.5	10	95.5%
	2 560	15	2	1	–	1	3	10	99.5%
	2 560	15	2	1	160	2	3	10	93.2%

From Table 121 it can be seen that sleep ratios of more than 90% is achieved in idle mode by NR devices.

TABLE 122

NR device sleep ratio in slot level (for connected mode)

	DRX cycle $T_{SC_ms} * M_{SC}$ (ms)	Number of SSB burst set	DRX-onDurationTimer (ms)	RRM measurement time per DRX (ms)	Transition time (ms)	Sleep ratio
RRC-Connected	320	1	2	3.5	10	95.2%
	320	1	10	3	10	92.8%
	2 560	1	100	3	10	95.6%
	10 240	1	1 600	3	10	84.2%

From Table 122 it can be seen that sleep ratios of more than 90% can be achieved in connected mode by NR devices.

It can therefore be concluded that NR devices can achieve high sleep ratio for both idle/inactive state and connected state in unloaded case.

The sleep duration for NR on the device side is given in [14], and the following is an extract of the text:

The sleep duration for NR UE in idle mode is 2 546 ms for paging cycle of 2 560 ms with the assumed parameters. The sleep duration of NR UE in connected state is 8 627 ms for paging cycle of 10 240 ms with the assumed parameters.

Consequently, NR devices can achieve very long sleep duration in both idle mode and connected mode.

It can therefore be concluded that NR meets the device side energy efficiency requirement.

II.5.10.2.2 LTE

II.5.10.2.2.1 LTE network side

The sleep ratio for LTE on the network side is given in [14], and Table 123 for the sleep ratio is taken from there.

TABLE 123

LTE network sleep ratio in subframe level (from [14])

Cell type	Sleep ratio
FeMBMS/Unicast-mixed cell	80%
MBMS-dedicated cell	93.75%

From Table 123 it can be seen that LTE networks can achieve high sleep ratio for FeMBMS/Unicast-mixed cell and MBMS-dedicated cell in unloaded case.

The sleep duration for LTE is given in [14], and Table 124 for the sleep duration is taken from there:

TABLE 124

LTE network sleep duration (ms) in subframe level (from [14])

Cell type	Sleep duration (ms)
FeMBMS/Unicast-mixed cell	4.00
MBMS-dedicated cell	39.00

From Table 124 it can be seen that MBMS-dedicated cells can achieve a sleep duration of 39 ms in the unloaded case.

Therefore, LTE meets network side energy efficiency requirement for FeMBMS/Unicast-mixed cell and MBMS-dedicated cell.

II.5.10.2.2 LTE device side

The sleep ratio for LTE on the device side is given in [14], and Table 125 and Table 126 for the sleep ratio is taken from there:

TABLE 125

LTE device sleep ratio in subframe level (for idle mode)

	Paging cycle $N_{PC_RF} * 10$ (ms)	Synchronization reception time per cycle(ms)	Synchronization cycle(ms)	Number of synchronization	RRM measurement time per DRX (ms)	Transition time (ms)	DL/UL subframe ratio	Sleep ratio
RRC-Idle	320	2	10*	1	6	10	1	93.1%
	320	2	10*	2	6	10	1	90.0%
	2 560	2	10*	1	6	10	1	99.1%
	2 560	2	10*	2	6	10	1	98.8%

From Table 125 it can be seen that more than 90% sleep ratio can be achieved in idle mode by LTE devices.

TABLE 126

LTE device sleep ratio in subframe level (for connected mode)

	DRX cycle T_{CYCLE_SF} (ms)	Synchronization reception time (ms)	Synchronization cycle (ms)	Number of synchronization	PDCCH reception time (ms)	RRM measurement time per DRX (ms)	DL/UL subframe ratio	Sleep ratio
RRC-Connected	320	2	–	1	10	6	1	91.9%
	320	2	10	2	10	6	0.5	85.6%
	2 560	2	–	1	100	6	1	95.5%
	2 560	2	10	2	100	6	0.5	91.2%
	10 240	2	–	1	1 600	6	1	84.2%

From Table 126 it can be seen that high sleep ratios can be achieved for different DRX cycles.

It can therefore be concluded that LTE devices can achieve high sleep ratio for both idle/inactive state and connected state in the unloaded case.

The sleep duration for NR on the device side is given in [14], and the following is an extract of the text:

Based on LTE DRX mechanism for idle mode and connected mode, the sleep duration for idle mode is 2538ms for paging cycle of 2560ms with the assumed parameters, and for connected mode, it is 8624ms for paging cycle of 10240ms with the assumed parameters.

Consequently, the LTE device can achieve very long sleep duration in both idle mode and connected mode.

It can therefore be concluded that LTE meets the device side energy efficiency requirement.

II.5.11 Reliability

The ITU-R minimum requirements on reliability are given in [1]. The following requirements and remarks are extracted from [1]:

Reliability relates to the capability of transmitting a given amount of traffic within a predetermined time duration with high success probability.

Reliability is the success probability of transmitting a layer 2/3 packet within a required maximum time, which is the time it takes to deliver a small data packet from the radio protocol layer 2/3 SDU ingress point to the radio protocol layer 2/3 SDU egress point of the radio interface at a certain channel quality.

This requirement is defined for the purpose of evaluation in the URLLC usage scenario.

The minimum requirement for the reliability is $1-10^{-5}$ success probability of transmitting a layer 2 PDU (protocol data unit) of 32 bytes within 1 ms in channel quality of coverage edge for the Urban Macro-URLLC test environment, assuming small application data (e.g. 20 bytes application data + protocol overhead).

Proponents are encouraged to consider larger packet sizes, e.g. layer 2 PDU size of up to 100 bytes.

Based on the reasoning given at the beginning of Section II.5.3 only 5G-NR RIT is evaluated.

II.5.11.1 Evaluation methodology and KPIs

The ITU-R minimum requirements on reliability are given in [1]. Specifically, reliability relates to the capability of transmitting a given amount of traffic within a predetermined time duration with high success probability. Reliability is the success probability of transmitting a layer 2/3 packet within a required maximum time, which is the time it takes to deliver a small data packet from the radio protocol layer 2/3 SDU ingress point to the radio protocol layer 2/3 SDU egress point of the radio interface at a certain channel quality. This requirement is defined for the purpose of evaluation in the URLLC usage scenario.

The minimum requirement for the reliability is $1-10^{-5}$ success probability of transmitting a layer 2 PDU (protocol data unit) of 32 bytes within 1 ms in channel quality of coverage edge for the Urban Macro-URLLC test environment, assuming small application data (e.g. 20 bytes application data + protocol overhead).

II.5.11.2 Simulation results

The basic evaluation parameters for downlink in Urban – URLLC are provided Table 127:

TABLE 127

Evaluation parameters

	Value
Inter-site distance	500 m
Macro BSs (3 TRxP each)	3
Bandwidth (MHz)	10
Packet size (bytes)	50

Two scenarios have been examined (Table 128) to determine the reliability metric for the evaluation configurations A and B (CF equals to 700 MHz and 4 GHz respectively). The first one considers a fixed amount of UEs and variable session periods (Figure 15) while the second one uses a fixed session period for every UE and varies the UE density in the area (Figure 16).

TABLE 128

Scenario configuration

	UE density	Session period
Scenario 1	10 UEs/TRxP	variable
Scenario 2	variable	1 000 sessions/hour/UE

FIGURE 15

Reliability for variable session periods

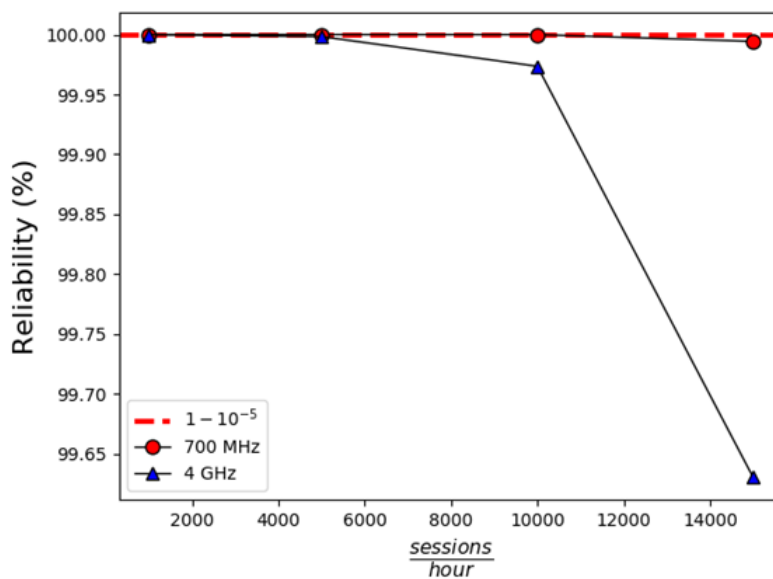
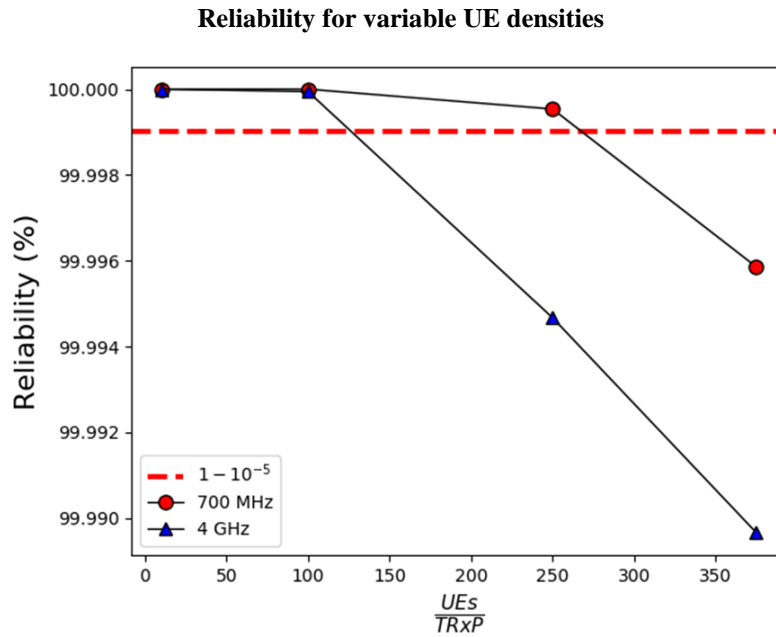


FIGURE 16



For uplink reliability, both evaluation configuration A and evaluation configuration B are evaluated. In the evaluation, one-shot PUSCH transmission with 14 OFDM symbols is assumed. The evaluation results are provided in Table 129.

TABLE 129

Uplink reliability evaluation results for evaluation configuration A and configuration B

Evaluation configuration	Antenna configuration	Sub-carrier spacing [kHz]	ITU Requirement	Channel model A		Channel model B	
				Channel condition	Reliability	Channel condition	Reliability
Evaluation configuration A	1T8R	60	99.999%	NLOS	99.999995%	NLOS	99.9999997%
Evaluation configuration B	1T16R	60		NLOS	99.99989%	NLOS	99.999992%

It can be observed that NR can meet the reliability requirement in evaluation configuration A and configuration B.

II.5.11.3 Summary

The provided results from the conducted system-level simulation show that NR fulfils the reliability constraint for several setups. Frequencies of 700 MHz and 4 GHz have been checked according to the ITU requirements. As it is expected, configuration B (as indicated by ITU) achieves lower reliability values than configuration A almost all the times due to the higher loss it faces. In general, it is shown that the minimum requirement for the reliability is $1-10^{-5}$ success probability of transmitting a layer 2 PDU (protocol data unit) of 32 bytes is achieved for up to almost 12,000 sessions/hour at 700 MHz and up to almost 5 000 sessions/hour at 4 GHz. Similarly, reliability is $1-10^{-5}$ success probability for UE densities for up to almost 250 UEs/TRx at 700 MHz and up to almost 120 UEs/TRx at 4 GHz.

II.5.12 Mobility

The ITU-R minimum requirements on mobility are given in [1]. The following requirements and remarks are extracted from [1]:

Mobility is the maximum mobile station speed at which a defined QoS can be achieved (in km/h).

The following classes of mobility are defined:

- *Stationary: 0 km/h*
- *Pedestrian: 0 km/h to 10 km/h*
- *Vehicular: 10 km/h to 120 km/h*
- *High speed vehicular: 120 km/h to 500 km/h.*

High speed vehicular up to 500 km/h is mainly envisioned for high speed trains. Table 1 defines the mobility classes that shall be supported in the respective test environments.

TABLE 1
Mobility classes

	<i>Test environments for eMBB</i>		
	<i>Indoor Hotspot – eMBB</i>	<i>Dense Urban – eMBB</i>	<i>Rural – eMBB</i>
<i>Mobility classes supported</i>	<i>Stationary, Pedestrian</i>	<i>Stationary, Pedestrian, Vehicular (up to 30 km/h)</i>	<i>Pedestrian, Vehicular, High speed vehicular</i>

A mobility class is supported if the traffic channel link data rate on the uplink, normalized by bandwidth, is as shown in Table 2. This assumes the user is moving at the maximum speed in that mobility class in each of the test environments.

This requirement is defined for the purpose of evaluation in the eMBB usage scenario.

TABLE 2
Traffic channel link data rates normalized by bandwidth

<i>Test environment</i>	<i>Normalized traffic channel link data rate (bit/s/Hz)</i>	<i>Mobility (km/h)</i>
<i>Indoor Hotspot – eMBB</i>	<i>1.5</i>	<i>10</i>
<i>Dense Urban – eMBB</i>	<i>1.12</i>	<i>30</i>
<i>Rural – eMBB</i>	<i>0.8</i>	<i>120</i>
	<i>0.45</i>	<i>500</i>

These values were defined assuming an antenna configuration as described in Report ITU-R M.2412-0.

Proponents are encouraged to consider higher normalized channel link data rates in the uplink. In addition, proponents are encouraged to consider the downlink mobility performance.

II.5.12.1 Evaluation methodology

The general evaluation method and procedure for mobility evaluation is defined in Report ITU-R M.2412. This procedure includes system-level simulation (SLS) part and link-level simulation (LLS) part. The following evaluation steps are extracted from Report ITU-R M.2412.

- Step 1:* Run uplink system-level simulations, identical to those for average spectral efficiency, and 5th percentile user spectral efficiency except for speeds taken from Table 4 of Report ITU-R M.2410-0, using link-level simulations and a link-to-system interface appropriate for these speed values, for the set of selected test environment(s) associated with the candidate RITs/SRITs and collect overall statistics for uplink SINR values, and construct CDF over these values for each test environment.
- Step 2:* Use the CDF for the test environment(s) to save the respective 50th-percentile SINR value.
- Step 3:* Run new uplink link-level simulations for the selected test environment(s) for either NLOS or LOS channel conditions using the associated speeds in Table 4 of Report ITU-R M.2410-0, as input parameters, to obtain link data rate and residual packet error ratio as a function of SINR. The link-level simulation shall use air interface configuration(s) supported by the proposal and take into account retransmission, channel estimation and phase noise impact.
- Step 4:* Compare the uplink spectral efficiency values (link data rate normalized by channel bandwidth) obtained from Step 3 using the associated SINR value obtained from Step 2 for selected test environments, with the corresponding threshold values in the Table 4 of Report ITU-R M.2410-0.
- Step 5:* The proposal fulfils the mobility requirement if the spectral efficiency value is larger than or equal to the corresponding threshold value and if also the residual decoded packet error ratio is less than 1%, for all selected test environments. For the selected test environment it is sufficient if one of the spectral efficiency values (using either NLOS or LOS channel conditions) fulfils the threshold.

For SLS part, the pre-processing SINR is used. The pre-processing SINR is defined on an Rx antenna port with respect to a Tx antenna port.

II.5.12.2 Results

The evaluation results are provided in Table 130.

- In Indoor Hotspot – eMBB test environment, evaluation configuration A (carrier frequency = 4 GHz) with 12TRxP is evaluated.
- In Dense Urban – eMBB test environment, evaluation configuration A (carrier frequency = 4 GHz) is evaluated.
- In Rural – eMBB test environment, evaluation configuration A (carrier frequency = 700 MHz) and evaluation configuration B (carrier frequency = 4 GHz) with different mobile speeds are evaluated.

Both channel model A and channel model B are applied in the simulation [3].

TABLE 130

Mobility evaluation results for different test environments

Test environment	ITU requirement (bit/s/Hz)	Evaluation configuration	Channel Model	50%-ile point of SINR CDF (dB)	Uplink SE (bit/s/Hz)			
					FDD		TDD	
					NLOS	LOS	NLOS	LOS
Indoor Hotspot – eMBB (12 TRxP)	1.5	Configuration A (4 GHz)	Channel model A	3.90	1.75	2.05	1.59	1.94
			Channel model B	3.95	1.75	2.07	1.60	1.95
Dense Urban – eMBB	1.12	Configuration A (4 GHz)	Channel model A	5.52	1.92	2.22	1.82	2.17
			Channel model B	5.32	1.89	2.19	1.79	2.06
Rural –eMBB (120 km/h)	0.8	Configuration A (700 MHz)	Channel model A	10.21	2.32	2.90	2.10	2.63
			Channel model B	10.14	2.31	2.90	2.09	2.63
		Configuration B (4 GHz)	Channel model A	4.66	1.30	1.74	1.18	1.57
			Channel model B	4.50	1.28	1.68	1.16	1.52
Rural –eMBB (500 km/h)	0.45	Configuration A (700 MHz)	Channel model A	9.67	2.07	2.64	1.88	2.39
			Channel model B	9.65	2.07	2.64	1.87	2.39
		Configuration B (4 GHz)	Channel model A	2.90	0.92	1.33	0.84	1.22
			Channel model B	2.72	0.91	1.33	0.83	1.22

It is observed that NR meets the mobility requirements in the test environments for eMBB.

II.5.13 Mobility interruption time

The ITU-R minimum requirements on mobility interruption time are given in [1]. The following requirements and remarks are extracted from [1]:

Mobility interruption time is the shortest time duration supported by the system during which a user terminal cannot exchange user plane packets with any base station during transitions.

The mobility interruption time includes the time required to execute any radio access network procedure, radio resource control signalling protocol, or other message exchanges between the mobile station and the radio access network, as applicable to the candidate RIT/SRIT.

This requirement is defined for the purpose of evaluation in the eMBB and URLLC usage scenarios.

The minimum requirement for mobility interruption time is 0 ms.

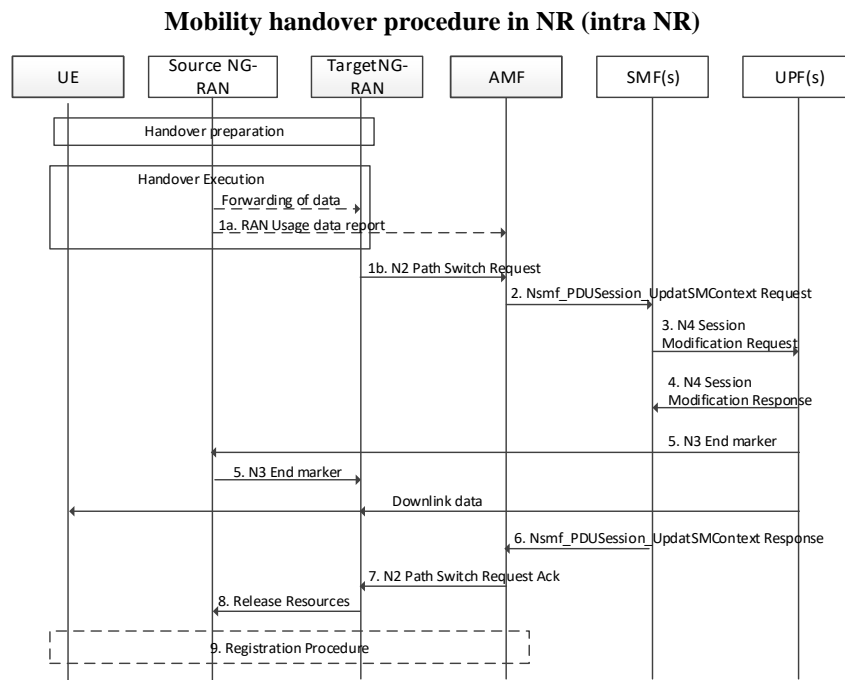
The ITU-R Guidelines for Evaluation report [3] is requesting in addition:

The procedure of exchanging user plane packets with base stations during transitions shall be described based on the proposed technology including the functions and the timing involved.

II.5.13.1 Mobility interruption time in NR and LTE

A typical mobility handover procedure includes procedures in the radio access network (RAN) as well as procedures in the core network (CN). Figure 17 shows a handover procedure in NR. It can be observed that there a handover preparation step and a handover execution step in the RAN network between the source next generation RAN (NG-RAN) and the target NG-RAN. During the handover execution procedure, the source NG-RAN needs to forward user plane data to the target NG-RAN using the Xn interface in NR. Next, a number of messaging steps occur between CN functions to modify the user plane data path for the user. Although LTE has a different system architecture, LTE is using similar procedures in LTE RAN and CN.

FIGURE 17



Depending on the types of the source cell and the target cell, handover scenarios can additionally include handover between intra-3GPP cells, and handover between 3GPP and non-3GPP cells. Intra-3GPP handover may include intra-NR cells, intra-LTE cells, NR and LTE cells, NR and UTRAN. In this case, the user only needs to ensure its synchronization to the target cell. Handover between 3GPP and non-3GPP cells may include NR- HRPD handover and NR- cdma2000 1X handover. In this case, there is an additional registration process to the target cell. The RAN procedure can result in delays in the order of a few milliseconds while the CN procedure can result in delays in the order of tens of milliseconds.

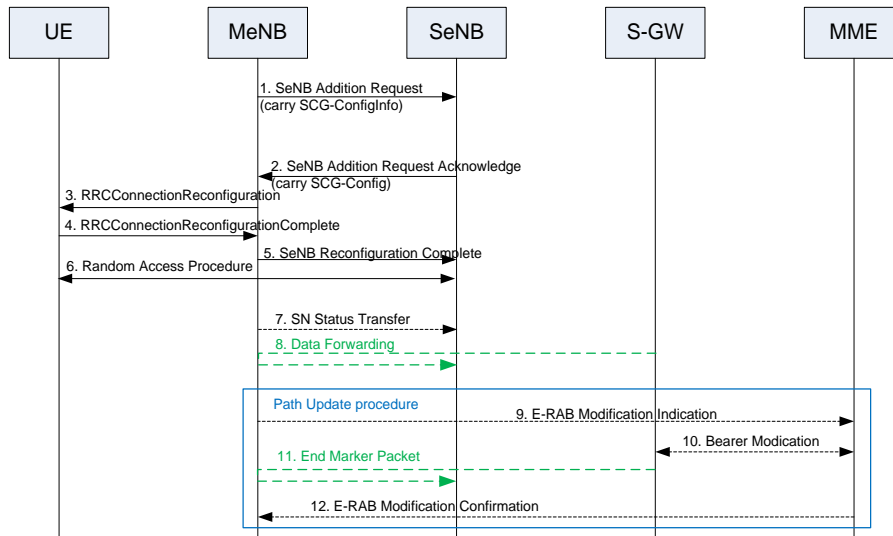
II.5.13.2 Means to minimize mobility interruption

In order to satisfy the requirement of 0 ms proposed by ITU-R, a number of means, which are based on the “Make-before-break Handover” and “Dual Connectivity” (DC) principle, have been proposed in Section 5.2.3.2.5 in [16] and Section 5.10 in [17]. With DC, before the

handover procedure starts, DC in the master base station (MeNB) will be configured and a secondary base station (SeNB) will be added to the UE.

The SeNB addition procedure and SeNB release procedures are shown in Figure 18, Figure 19, and Figure 20. The SeNB addition procedure is initiated by the MeNB and is used to establish a UE context at the SeNB in order to provide radio resources from the SeNB to the UE. This procedure is used to add at least the first cell (PSCell) of the SCG. Figure 5.10.2.2-1 shows the SeNB addition procedure. The detailed description of each step is found in Section 10.1.2.8.1 in 3GPP TS36.300.

FIGURE 18
SeNB Addition procedure



The SeNB Release procedure may be initiated either by the MeNB or by the SeNB and is used to initiate the release of the UE context at the SeNB. It does not necessarily need to involve signaling towards the UE, e.g., RRC connection re-establishment due to Radio Link Failure in MeNB.

FIGURE 19
SeNB Release procedure – MeNB initiated

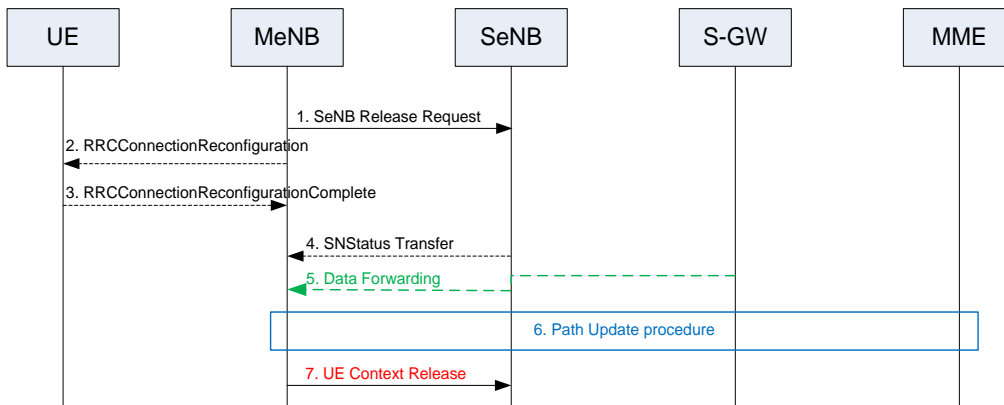
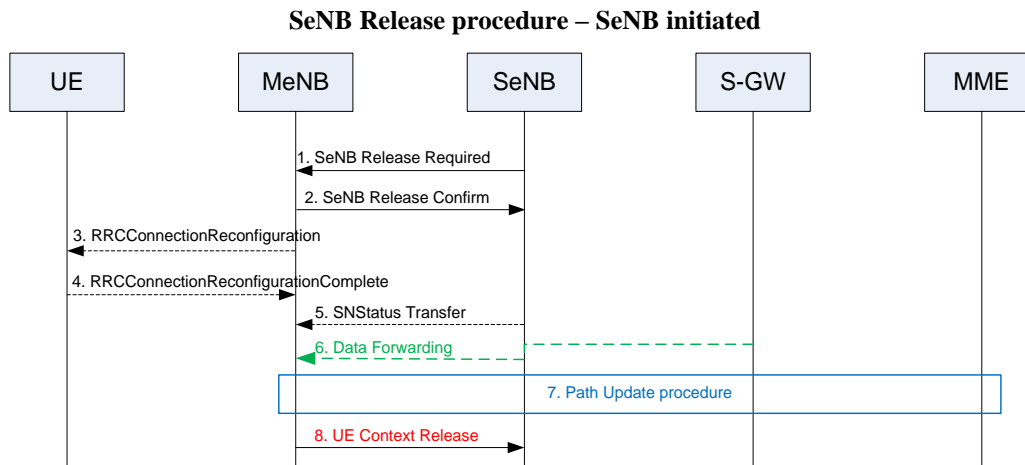


FIGURE 20



The DC principle can be applied to intra-NR handover, intra-LTE handover, inter-RAT handover, and inter-system handover. It is observed that during these procedures, the UE can always exchange user plane packets with MeNB during transitions. Therefore, 0ms mobility interruption time is achieved by LTE for the DC mobility scenario.

II.5.13.2.1 Intra-NR handover

Network controlled mobility applies to UEs in RRC_CONNECTED and is categorized into two types of mobility.

The first type is cell-level mobility, which requires explicit RRC signaling to be triggered, i.e. handover. For inter-gNB handover, handover request, handover acknowledgement, handover command, handover complete procedure are supported between source gNB and target gNB. Using the “Make-before-break Handover” and DC principle, the release of the resources at the source gNB during the handover completion phase is triggered by the target gNB. The second type is beam-level mobility, which does not require explicit RRC signaling to be triggered. Beam-level mobility is handled by lower layers and RRC is not required to know which beam is being used at a given point in time.

In both types, a UE needs to perform measurement to assist the mobility procedure. In RRC_CONNECTED, the UE measures multiple beams (at least one) of a cell and the measurements results (power values) are averaged to derive the cell quality. In doing so, the UE is configured to consider a subset of the detected beams: The N best beams above an absolute threshold. Filtering takes place at two different levels: at the physical layer to derive beam quality and then at RRC level to derive cell quality from multiple beams. Cell quality from beam measurements is derived in the same way for the serving cell(s) and for the non-serving cell(s). Measurement reports may contain the measurement results of the X best beams if the UE is configured to do so by the gNB. In addition, data forwarding, in-sequence delivery and duplication avoidance at handover can be guaranteed between target gNB and source gNB. For more details, refer to [18] sub-clauses 9.2.3 & 9.3.

II.5.13.2.2 Intra-LTE handover

In E-UTRAN RRC_CONNECTED state, network-controlled UE-assisted handovers and DC specific activities are performed and various DRX cycles are supported. Handover procedures, like processes that precede the final handover decision on the source network side (control and evaluation of UE and eNB measurements taking into account certain UE specific roaming and access restrictions), preparation of resources on the target network side,

commanding the UE to the new radio resources and finally releasing resources on the (old) source network side with the DC principle. It contains mechanisms to transfer context data between evolved nodes, and to update node relations on C-plane and U-plane.

Measurements to be performed by a UE for intra/inter-frequency mobility can be controlled by E-UTRAN, using broadcast or dedicated control. In RRC_IDLE state, a UE shall follow the measurement parameters defined for cell reselection specified by the E-UTRAN broadcast. The use of dedicated measurement control for RRC_IDLE state is possible through the provision of UE specific priorities. In RRC_CONNECTED state, a UE shall follow the measurement configurations specified by RRC directed from the E-UTRAN (e.g. as in UTRAN MEASUREMENT_CONTROL). In RRC_IDLE and RRC_CONNECTED the UE may be configured to monitor some UTRA or E-UTRA carriers according to reduced performance requirements as specified in [19]. For more details, refer to [20] sub-clauses 10.1 & 10.2.

II.5.13.2.3 Inter-RAT handover

Intra 5GC inter RAT mobility is supported between NR and E-UTRA. Inter RAT measurements in NR are limited to E-UTRA and the source RAT should be able to support and configure target RAT measurement and reporting. The in-sequence and lossless handover is supported for the handover between gNB and ng-eNB. Both Xn and NG based inter-RAT handover between NG-RAN nodes is supported. Whether the handover is over Xn or CN is transparent to the UE. The target RAT receives the UE NG-C context information and based on this information configures the UE with a complete RRC message and full configuration (not delta).

II.5.13.2.4 Inter-System handover

Inter-system handover is supported between 5G Core Network (5GC) and EPC. Handover between NR in 5GC and E-UTRA in EPC is supported via inter-RAT handover. Handover between E-UTRA in 5GC and E-UTRA in EPC is supported via intra-E-UTRA handover with change of CN type. The source eNB/ng-eNB decides handover procedure to trigger (e.g. via the same CN type or to the other CN type). UE has to know the target CN type from the handover command during intra-LTE inter-system handover, intra-LTE intra-system handover.

II.5.13.3 Evaluation of the proposal

The proposal is using means like “Make-before-break Handover” and DC to mitigate Mobility interruption time. This ensures that the minimum ITU-R requirement above of 0 ms mobility interruption time is fulfilled.

II.5.14 Bandwidth

The ITU-R minimum requirements on supported bandwidth is given in [1]. The following requirements and additional remarks are following from [1]:

Bandwidth is the maximum aggregated system bandwidth. The bandwidth may be supported by single or multiple radio frequency (RF) carriers. The bandwidth capability of the RIT/SRIT is defined for the purpose of IMT-2020 evaluation.

The requirement for bandwidth is at least 100 MHz.

The RIT/SRIT shall support bandwidths up to 1 GHz for operation in higher frequency bands (e.g. above 6 GHz).

Proponents are encouraged to consider extensions to support operation in wider bandwidths considering the research targets expressed in Recommendation ITU-R M.2083.

The RIT/SRIT shall support scalable bandwidth. Scalable bandwidth is the ability of the candidate RIT/SRIT to operate with different bandwidths.

The Table 131 and Table 132 are summarizing the characteristics of the NR RIT and the LTE SRIT of 5G.

TABLE 131
Characteristics template for SRIT of “5G” (Release 15 and beyond)

ITU-R requirements	NR component RIT	LTE component SRIT
Below 6 GHz: at least 100 MHz	<p>[4], [8], Section 5.2.3.2.8.2</p> <p>One component carrier supports a scalable bandwidth, 5, 10, 15, 20, 25, 40, 50, 60, 80, 100 MHz for frequency range 450 MHz to 6 000 MHz (see [11] for the actual support of bandwidth for each band), with guard band ratio from 20% to 2%; and a scalable bandwidth, 50, 100, 200, 400 MHz for frequency range 24250 – 52600 MHz (see [11] for the actual support of bandwidth for each band), with guard band ratio from 8% to 5%.</p> <p>By aggregating multiple component carriers, transmission bandwidths up to 6.4 GHz are supported to provide high data rates. Component carriers can be either contiguous or non-contiguous in the frequency domain. The number of component carriers transmitted and/or received by a mobile terminal can vary over time depending on the instantaneous data rate.</p> <p>[4], [8], Section 5.2.3.2.8.5</p> <p>The 3 dB bandwidth is not part of the specifications, however:</p> <ul style="list-style-type: none"> – The minimum 99% channel bandwidth (occupied bandwidth of single component carrier) is <ul style="list-style-type: none"> • 5 MHz for frequency range 	<p>[4], [8], Section 5.2.3.2.8.2</p> <p>One component carrier supports a scalable bandwidth, 1.4, 3, 5, 10, 15 and 20 MHz, with guard band ratio from 23% to 10% (see [12] sub-clause 5.6 for more details).</p> <p>By aggregating multiple component carriers, transmission bandwidths up to 640 MHz are supported to provide the high data rates. Component carriers can be either contiguous or non-contiguous in the frequency domain. The number of component carriers transmitted and/or received by a mobile terminal can vary over time depending on the instantaneous data rate.</p> <p>For NB-IoT, the channel bandwidth is not scalable. There is not aggregation of multiple NB-IoT carriers – see item [4], [8] Section 5.2.3.2.8.1 for more details.</p> <p>For eMTC, the above scalable bandwidth from 1.4 to 20 MHz is supported. The eMTC UE can have a narrower RF bandwidth than the cell is configured with. Category M1 UE has a bandwidth of 1.4 MHz, and category M2 UE has 5 MHz bandwidth.</p> <p>[4], [8], Section 5.2.3.2.8.5</p> <p>The 3 dB bandwidth is not part of the specifications, however:</p> <ul style="list-style-type: none"> – The minimum 99% channel bandwidth (occupied bandwidth of single component carrier) is 1.4 MHz.

	<p>450–6 000 MHz;</p> <ul style="list-style-type: none"> – The maximum 99% channel bandwidth (occupied bandwidth of single component carrier) is <ul style="list-style-type: none"> • 100 MHz for frequency range 450–6 000 MHz; – Multiple component carriers can be aggregated to achieve up to 6.4 GHz of transmission bandwidth. 	<ul style="list-style-type: none"> – The maximum 99% channel bandwidth (occupied bandwidth of single component carrier) is 20 MHz. – Multiple component carriers can be aggregated to achieve up to 640 MHz of transmission bandwidth. <p>For NB-IoT, the 99% channel bandwidth is 0.2 MHz.</p>
<p>Above 6 GHz: up to 1 GHz</p>	<p>[4], [8], Section 5.2.3.2.8.2</p> <p>One component carrier supports a scalable bandwidth, 5, 10, 15, 20, 25, 40, 50, 60, 80, 100 MHz for frequency range 450 MHz to 6 000 MHz (see [11] for the actual support of bandwidth for each band), with guard band ratio from 20% to 2%; and a scalable bandwidth, 50, 100, 200, 400 MHz for frequency range 24 250-52 600 MHz (see [11] for the actual support of bandwidth for each band), with guard band ratio from 8% to 5%.</p> <p>By aggregating multiple component carriers, transmission bandwidths up to 6.4 GHz are supported to provide high data rates. Component carriers can be either contiguous or non-contiguous in the frequency domain. The number of component carriers transmitted and/or received by a mobile terminal can vary over time depending on the instantaneous data rate.</p> <p>[4], [8], Section 5.2.3.2.8.5</p> <p>The 3 dB bandwidth is not part of the specifications, however:</p> <ul style="list-style-type: none"> – The minimum 99% channel bandwidth (occupied bandwidth of single component carrier) is <ul style="list-style-type: none"> • 50 MHz for frequency range 24 250-52 600 MHz – The maximum 99% channel bandwidth (occupied bandwidth of single component carrier) is <ul style="list-style-type: none"> • 400 MHz for frequency range 24 250-52 600 MHz. 	<p>[4], [8], Section 5.2.3.2.8.2</p> <p>No higher frequency bands above 6 GHz are supported by the LTE component.</p>

	<ul style="list-style-type: none"> - Multiple component carriers can be aggregated to achieve up to 6.4 GHz of transmission bandwidth. 	
Minimum amount of spectrum	<p>[4], [8], Section 5.2.3.2.8.4</p> <ul style="list-style-type: none"> - The minimum amount of paired spectrum is 2 x 5 MHz. - The minimum amount of unpaired spectrum is 5 MHz. 	<p>[4], [8], Section 5.2.3.2.8.4</p> <ul style="list-style-type: none"> - The minimum amount of paired spectrum is 2 x 1.4 MHz, and the minimum amount of unpaired spectrum is 1.4 MHz, except for NB-IoT. - For NB-IoT, the minimum amount of unpaired spectrum is 0.2 MHz.

TABLE 132

Characteristics template for NR RIT of “5G” (Release 15 and beyond)

ITU-R requirements	NR RIT
Below 6 GHz: at least 100 MHz	<p>[4], [8], Section 5.2.3.2.8.2</p> <p>One component carrier supports a scalable bandwidth, 5, 10, 15, 20, 25, 40, 50, 60, 80, 100 MHz for frequency range 450 MHz to 6 000 MHz (see [11] for the actual support of bandwidth for each band), with guard band ratio from 20% to 2%; and a scalable bandwidth, 50, 100, 200, 400MHz for frequency range 24 250-52 600 MHz (see [11] for the actual support of bandwidth for each band), with guard band ratio from 8% to 5%.</p> <p>By aggregating multiple component carriers, transmission bandwidths up to 6.4 GHz are supported to provide high data rates. Component carriers can be either contiguous or non-contiguous in the frequency domain. The number of component carriers transmitted and/or received by a mobile terminal can vary over time depending on the instantaneous data rate.</p> <p>[4], [8], Section 5.2.3.2.8.5</p> <p>The 3 dB bandwidth is not part of the specifications, however:</p> <ul style="list-style-type: none"> - The minimum 99% channel bandwidth (occupied bandwidth of single component carrier) is: <ul style="list-style-type: none"> • 5 MHz for frequency range 450-6 000 MHz; - The maximum 99% channel bandwidth (occupied bandwidth of single component carrier) is: <ul style="list-style-type: none"> • 100 MHz for frequency range 450-6 000 MHz; <p>Multiple component carriers can be aggregated to achieve up to 6.4 GHz of transmission bandwidth.</p>
Above 6 GHz: up to 1 GHz	[4], [8], Section 5.2.3.2.8.2

	<p>One component carrier supports a scalable bandwidth, 5, 10, 15, 20, 25, 40, 50, 60, 80, 100 MHz for frequency range 450 MHz to 6 000 MHz (see [11] for the actual support of bandwidth for each band), with guard band ratio from 20% to 2%; and a scalable bandwidth, 50, 100, 200, 400MHz for frequency range 24 250-52 600 MHz (see [11] for the actual support of bandwidth for each band), with guard band ratio from 8% to 5%.</p> <p>By aggregating multiple component carriers, transmission bandwidths up to 6.4 GHz are supported to provide high data rates. Component carriers can be either contiguous or non-contiguous in the frequency domain. The number of component carriers transmitted and/or received by a mobile terminal can vary over time depending on the instantaneous data rate.</p> <p>[4], [8], Section 5.2.3.2.8.5</p> <p>The 3 dB bandwidth is not part of the specifications, however:</p> <ul style="list-style-type: none"> – The minimum 99% channel bandwidth (occupied bandwidth of single component carrier) is <ul style="list-style-type: none"> • 50 MHz for frequency range 24 250-52 600 MHz – The maximum 99% channel bandwidth (occupied bandwidth of single component carrier) is <ul style="list-style-type: none"> • 400 MHz for frequency range 24 250-52 600 MHz. <p>Multiple component carriers can be aggregated to achieve up to 6.4 GHz of transmission bandwidth.</p>
Minimum amount of spectrum	<p>[4], [8], Section 5.2.3.2.8.4</p> <ul style="list-style-type: none"> – The minimum amount of paired spectrum is 2 x 5 MHz. – The minimum amount of unpaired spectrum is 5 MHz.

The combination of the 3GPP submissions on

- SRIT of “5G” (Release 15 and beyond) including NR component RIT and LTE component RIT and
- NR RIT of “5G” (Release 15 and beyond)

is supporting the minimum requirements on bandwidth of

- at least 100 MHz for frequency bands below 6 GHz
- and up to 1 GHz for higher frequency bands e.g., above 6 GHz.

By means of carrier aggregation higher bandwidth up to 6.4 GHz are possible.

The bandwidth is scalable in several steps.

The 3GPP submission is fulfilling the minimum requirements according to [1].

II.5.15 Support of wide range of services

The ITU-R requirements on “support of wide range of services” are given in [2] and specifically section 3.1 Services:

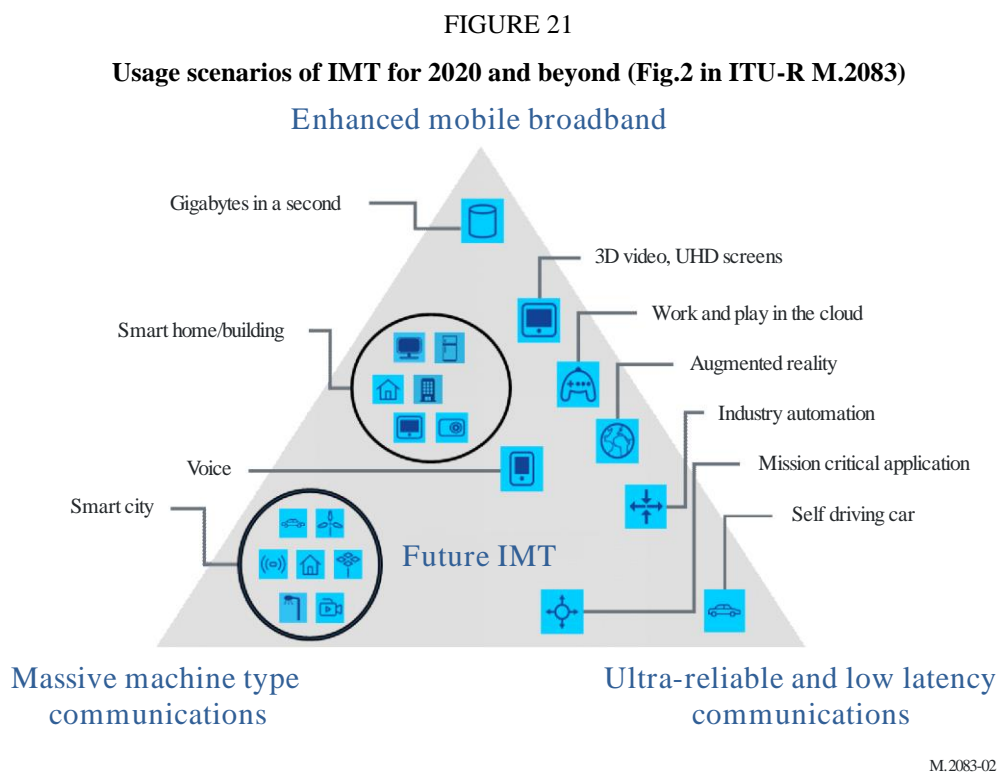
Recommendation ITU-R M.2083 – IMT Vision – Framework and overall objectives of the future development of IMT for 2020 and beyond, envisaged three usage scenarios for IMT-2020:

- *Enhanced Mobile Broadband (eMBB).*
- *Ultra-reliable and low latency communications (URLLC).*
- *Massive machine type communications (mMTC).*

Diverse services and applications for the three usage scenarios are envisaged, as shown in Fig. 2 in Recommendation ITU-R M.2083.

IMT-2020 RIT/SRIT shall support a wide range of services across different usage scenarios, for which the evaluation methodology is found in § 7.3.3 of Report ITU-R M.2412-0.

For convenience, Figure 21 in Recommendation ITU-R M.2083 is given below [21]:



The evaluation by means of inspection of “Support of Wide Range of Services” is using a list of capabilities of IMT-2020 according to page 4 of [3]:

IMT-2020 systems support low to high mobility applications and much enhanced data rates in accordance with user and service demands in multiple user environments. IMT-2020 also has capabilities for enabling massive connections for a wide range of services, and guarantee ultra-reliable and low latency communications for future deployed services even in critical environments.

The capabilities of IMT-2020 include:

- (1) *very high peak data rate;*
- (2) *very high and guaranteed user experienced data rate;*
- (3) *quite low air interface latency;*
- (4) *quite high mobility while providing satisfactory quality of service;*
- (5) *enabling massive connection in very high density scenario;*
- (6) *very high energy efficiency for network and device side;*
- (7) *greatly enhanced spectral efficiency;*
- (8) *significantly larger area traffic capacity;*
- (9) *high spectrum and bandwidth flexibility;*
- (10) *ultra high reliability and good resilience capability;*
- (11) *enhanced security and privacy.*

These features enable IMT-2020 to address evolving user and industry needs.

The capabilities of IMT-2020 systems are being continuously enhanced in line with user and industry trends, and consistent with technology developments.

Moreover, in section 7.3.3 of [3], the inspection approach is described through the statement with the referenced reports [1] and [21]:

There are elements of the minimum technical performance requirements identified within Report ITU-R M.2410-0 that indicate whether or not the candidate RITs/SRITs are capable of enabling certain services and performance targets, as envisioned in Recommendation ITU-R M.2083.

The support of a wide range of services is verified by inspection of the candidate RITs/SRITs ability to meet the minimum technical performance requirements for various usage scenarios and their associated test environments.

The characteristics evaluated in the current report correspond to the minimum technical requirements that have to be fulfilled by 3GPP RIT/SRIT submission and also correspond to capabilities items (1) to (10) of the above list. Minimum requirements of the current evaluation report do not include security and privacy issues. Therefore, 3GPP RIT/SRIT submission fulfils the requirement for “support of wide range of services” if all the other characteristics meet the requirements defined by ITU.

II.5.15.1 3GPP description template

The characteristics template for SRIT and NR RIT of “5G” (Release 15 and beyond) are given below in Table 133 and Table 134 with the references [22] and [23]. The description of the SRIT and NR RIT 3GPP proposals for this evaluation characteristic is identical.

TABLE 133

Characteristics template for Support of Wide Range of Services for SRIT 5G

5.2.3.2.23	Support for wide range of services SRIT of 5G
5.2.3.2.23.1	Describe what kind of services/applications can be supported in each usage scenarios in Recommendation ITU-R M.2083 (eMBB, URLLC, and mMTC). <i>This proposal supports a wide range of services across the diverse usage scenarios including eMBB, URLLC, and mMTC envisaged in Recommendation ITU-R M.2083.</i>

	<p><i>The example services supported by this proposal include the services defined in Recommendation ITU-R M.1822, [22.261], and other services, such as</i></p> <ul style="list-style-type: none"> – <i>eMBB services including conversational services (including basic/ rich conversational services, low delay conversational services), interactive (with high and low delay) services, streaming (live/non-live) services, and other high data rate services; for stationary users, pedestrian users, to high speed train/vehicle users.</i> – <i>URLLC services including transportation safety, smart grid, mobile health application, wireless industry automation, etc.</i> – <i>mMTC services including smart city, smart home applications, and other machine-type communication (also known as Machine-to-Machine (M2M)) services.</i>
<p>5.2.3.2.23.2</p>	<p>Describe any capabilities/features to flexibly deploy a range of services across different usage scenarios (eMBB, URLLC, and mMTC) in an efficient manner, (e.g., a proposed RIT/SRIT is designed to use a single continuous or multiple block(s) of spectrum).</p> <p><u>For NR component RIT:</u></p> <p><i>NR is capable of deploying a range of services across different usage scenarios. While the specification does not match any physical layer functionality to any service, different components can benefit different services in specific usage scenarios.</i></p> <p><i>Specifically, the following low latency structures cater especially to the URLLC services</i></p> <ul style="list-style-type: none"> – <i>Front loaded DMRS allows for the channel estimate to be ready before the full data block is received</i> – <i>Frequency-first mapping of data bits to physical resources allows for the channel decoder to operate in a pipelined fashion, starting to decode the data block immediately when the first symbol has been received</i> – <i>Very tight UE processing time budget especially targeted for ultra-low latency device types</i> – <i>Very short scheduling interval achieved with both high subcarrier spacing (short symbol duration) and the possibility to schedule short time intervals only</i> – <i>At least an UL transmission scheme without scheduling grant is supported to reduce UL latency.</i> <p><i>mMTC services can benefit from the following components</i></p> <ul style="list-style-type: none"> – <i>DFT-spreading and Pi/2 BPSK modulation for reduced PAPR and increased average Tx power for better coverage</i> – <i>Slot aggregation for both control and data for better coverage</i> – <i>High-aggregation level downlink control for better coverage</i> – <i>RRC inactive state for optimized signalling overhead when moving to active state</i> – <i>Extended DRX cycle for RRC active state to improve battery life</i> – <i>Support for narrow-band (low-cost) UEs within a wide-band carrier</i> <p><i>URLLC, eMBB and mMTC services can coexist within the same spectrum in both time and frequency domain in multiplexed manner. URLLC can pre-empt ongoing eMBB/mMTC transmissions, if necessary, and URLLC services can be mapped to e.g. a shorter allocation duration for lower latency by small number of scheduled symbols, as well as by using higher sub-carrier spacing and thus allocation duration for the same number of scheduled symbols, while eMBB services can be mapped to do the opposite. Different sub-carrier spacings and scheduling interval durations that are appropriate to the desired service type (e.g., different latency and data rate requirements) can coexist in a single carrier with no need for fixed divisions within the carrier, by e.g., using spectral refinement techniques such as filtering, windowing, etc. with the designated waveforms for NR.</i></p> <p><u>For LTE component RIT:</u></p> <p><i>LTE is capable of deploying a range of services across different usage scenarios. While the specification does not match any physical layer functionality to any service, different components can benefit different services in specific usage scenarios.</i></p> <p><i>Specifically, the following low latency components are enabled</i></p> <ul style="list-style-type: none"> – <i>Frequency-first mapping of data bits to physical resources allows for the channel decoder to operate in a pipelined fashion, starting to decode the data block immediately when the first symbol has been received</i>

	<ul style="list-style-type: none"> – Short scheduling interval achieved with short TTI length (see item 5.2.3.2.7 and reference therein) – Configurable shorter uplink semi-persistent-scheduling (SPS) interval (can be less than 10 subframes, e.g. 1ms) is introduced to reduce uplink latency for SPS. – Uplink skipping mechanism is introduced for SPS to avoid resource release such that the latency of waiting for the next SPS uplink grant can be avoided. <p><i>mMTC services are supported by NB-IoT / eMTC</i></p> <ul style="list-style-type: none"> – DFT-spreading and Pi/2 BPSK (for both NB-IoT and eMTC) and Pi/4 QPSK (for NB-IoT) modulation for reduced PAPR for better coverage – Repetition of a transmission for both control and data for better coverage – RV cycling to improve code rates for better coverage – Cyclic repetition to enable symbol-level I/Q combining and to improve frequency/timing offset tracking for better coverage – Frequency hopping in eMTC to improve frequency diversity for better coverage – High-aggregation level downlink control in eMTC for better coverage – Small data transmission during random access without moving to RRC connected mode for optimized signalling overhead – PSM mode and extended DRX cycle for RRC IDLE mode to improve battery life – Support for narrow-band (low-cost) UEs within a wide-band carrier system; 1.08 MHz for eMTC and 180kHz for NB-IoT. – Support for single sub-carrier and sub-PRB (3 and 6 subcarriers) uplink transmission in NB-IoT, and sub-PRB (3 and 6 subcarriers) transmission for eMTC, to increase connection density in extended coverage <p><i>LTE is capable of deploying a range of services, e.g., mMTC and eMBB services, on a single continuous block of spectrum, by e.g., eMTC in-band operation or NB-IoT with in-band / guard-band operation (see item 5.2.3.2.8.1 for more details).</i></p>
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TABLE 134

Characteristics template for Support of Wide Range of Services for NR RIT 5G

5.2.3.2.23	Support for wide range of services NR RIT of 5G
5.2.3.2.23.1	<p>Describe what kind of services/applications can be supported in each usage scenarios in Recommendation ITU-R M.2083 (eMBB, URLLC, and mMTC).</p> <p><i>This proposal targets to support a wide range of services across the diverse usage scenarios including eMBB, URLLC, and mMTC envisaged in Recommendation ITU-R M.2083.</i></p> <p><i>The example services supported by this proposal include the services defined in Recommendation ITU-R M.1822, [22.261], and other services, such as</i></p> <ul style="list-style-type: none"> – <i>eMBB services including conversational services (including basic/ rich conversational services, low delay conversational services), interactive (with high and low delay) services, streaming (live/non-live) services, and other high data rate services; for stationary users, pedestrian users, to high speed train/vehicle users.</i> – <i>URLLC services including transportation safety, smart grid, mobile health application, wireless industry automation, etc.</i> – <i>mMTC services including smart city, smart home applications, and other machine-type communication (also known as Machine-to-Machine (M2M)) services.</i>
5.2.3.2.23.2	<p>Describe any capabilities/features to flexibly deploy a range of services across different usage scenarios (eMBB, URLLC, and mMTC) in an efficient manner, (e.g., a proposed RIT/SRIT is designed to use a single continuous or multiple block(s) of spectrum).</p> <p><i>NR is capable of deploying a range of services across different usage scenarios. While the specification does not match any physical layer functionality to any service, different components can benefit different services in specific usage scenarios.</i></p>

<p><i>Specifically, the following low latency structures cater especially to the URLLC services</i></p> <ul style="list-style-type: none">– <i>Front loaded DMRS allows for the channel estimate to be ready before the full data block is received</i>– <i>Frequency-first mapping of data bits to physical resources allows for the channel decoder to operate in a pipelined fashion, starting to decode the data block immediately when the first symbol has been received</i>– <i>Very tight UE processing time budget especially targeted for ultra-low latency device types</i>– <i>Very short scheduling interval achieved with both high subcarrier spacing (short symbol duration) and the possibility to schedule short time intervals only</i>– <i>At least an UL transmission scheme without scheduling grant is supported to reduce UL latency.</i> <p><i>mMTC services can benefit from the following components</i></p> <ul style="list-style-type: none">– <i>DFT-spreading and Pi/2 BPSK modulation for reduced PAPR and increased average Tx power for better coverage</i>– <i>Slot aggregation for both control and data for better coverage</i>– <i>High-aggregation level downlink control for better coverage</i>– <i>RRC inactive state for optimized signalling overhead when moving to active state</i>– <i>Extended DRX cycle for RRC active state to improve battery life</i>– <i>Support for narrow-band (low-cost) UEs within a wide-band carrier</i> <p><i>URLLC, eMBB and mMTC services can coexist within the same spectrum in both time and frequency domain in multiplexed manner. URLLC can pre-empt ongoing eMBB/mMTC transmissions, if necessary, and URLLC services can be mapped to e.g. a shorter allocation duration for lower latency by small number of scheduled symbols, as well as by using higher sub-carrier spacing and thus allocation duration for the same number of scheduled symbols, while eMBB services can be mapped to do the opposite. Different sub-carrier spacings and scheduling interval durations that are appropriate to the desired service type (e.g., different latency and data rate requirements) can coexist in a single carrier with no need for fixed divisions within the carrier, by e.g., using spectral refinement techniques such as filtering, windowing, etc. with the designated waveforms for NR.</i></p>
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The Recommendation ITU-R M.1822 [22] is used as a reference as in the Table 133 and Table 134 above especially for the eMBB services definition although this recommendation was already finalized in 2007 and refers to IMT Advanced. Thus, the 3GPP proposal for the eMBB usage scenario categorizes services as conversational, interactive and streaming.

II.5.15.2 Conclusion

The combination of the 3GPP submissions on

- SRIT of 5G (Release 15 and beyond) including NR component RIT and LTE component RIT and
- NR RIT of 5G (Release 15 and beyond)

support diverse services and applications in the three usage scenarios namely, eMBB, URLLC, mMTC meeting the requirements of ITU in [1].

All the characteristics evaluated in this report meet the minimum requirements in order to support wide range of services in various scenarios and environments.

II.5.16 Supported spectrum bands

The ITU-R minimum requirements on supported spectrum bands are given in [2]. The following requirements and additional remarks are following from [2]:

The following frequency bands have been identified for IMT in the ITU Radio Regulations by WARC-92, WRC-2000, WRC-07, WRC-12 and WRC-15.

450-470 MHz (see No. 5.286AA of the Radio Regulations (RR))

470-698 MHz (see RR Nos. 5.295, 5.308, 5.296A)

694/698-960 MHz (see RR Nos. 5.313A, 5.317A)

1 427-1 518 MHz (see RR Nos. 5.341A, 5.346, 5.341B, 5.341C, 5.346A)

1 710-2 025 MHz (see RR Nos. 5.384A, 5.388)

2 110-2 200 MHz (see RR No. 5.388)

2 300-2 400 MHz (see RR No. 5.384A)

2 500-2 690 MHz (see RR No. 5.384A)

3 300-3 400 MHz (see RR Nos. 5.429B, 5.429D, 5.429F)

3 400-3 600 MHz (see RR Nos. 5.430A, 5.431B, 5.432A, 5.432B, 5.433A)

3 600-3 700 MHz (see RR No. 5.434)

4 800-4 990 MHz (see RR Nos. 5.441A, 5.441B)

Frequency arrangements for these bands identified before WRC-15 are incorporated in Recommendation ITU-R M.1036-5. Work on frequency arrangements for the frequency bands that were identified by WRC-15 is currently ongoing in ITU-R.

Administrations would endeavour to make spectrum available from the frequency bands listed above.

Recommendation ITU-R M.2083 indicates a need of higher frequency bands to support the different usage scenarios with a requirement of several hundred MHz up to at least 1 GHz bandwidth corresponding wider and contiguous spectrum ability. Further, the development of IMT-2020 is expected to enable new use cases and applications associated with radio traffic growth.

Taking into account the IMT-2020 deployment to be expected from the year 2020 onwards, Administrations would endeavour to make spectrum available from the higher frequency bands in a timely manner.

The requirements related to spectrum are in the compliance templates in § 5.2.4.2.

Table 135 and Table 136 show the supported bands compared to the minimum requirements.

TABLE 135

Characteristics template for NR RIT and LTE SRIT of “5G” (Release 15 and beyond)

ITU-R [2] [MHz]	<u>For 5G NR component RIT:</u> [4], [8], Section 5.2.3.2.8.3 <i>The following frequency bands will be supported, in accordance with spectrum requirements defined by Report ITU-R M.2411-0. Introduction of other ITU-R IMT identified bands are not precluded in the future. 3GPP technologies are also defined as appropriate to operate in other frequency arrangements and bands.</i>			<u>For LTE component SRIT:</u> [4], [8], Section 5.2.3.2.8.3 <i>The following frequency bands are currently specified, in accordance with spectrum requirements defined by Report ITU-R M.2411-0. Introduction of other ITU-R IMT identified bands are not precluded in the future. 3GPP technologies are also defined as appropriate to operate in other frequency arrangements and bands. Detailed information on the following bands can be found in [12] sub-clause 5.5.</i>		
	Band number	UL operating band	DL operating band	Band number	UL operating band	DL operating band
450 – 470 MHz	-	-	-	n73 n72 n31	450 – 455 MHz 451 – 456 MHz 452.5 – 457.5 MHz	460 – 465 MHz 461 – 466 MHz 462.5 – 467.5 MHz
470 – 698 MHz	n71	663 – 698 MHz	617 – 652 MHz	n71	663 – 698 MHz	617 – 652 MHz
694/698 – 960 MHz	n12 n28 n83 n5 n20 n82 n8 n81	699 – 716 MHz 703 – 748 MHz 703 – 748 MHz 824 – 849 MHz 832 – 862 MHz 832 – 862 MHz 880 – 915 MHz 880 – 915 MHz	729 – 746 MHz 758 – 803 MHz N/A 869 – 894 MHz 791– 821 MHz N/A 925 – 960 MHz N/A	n85 n12 n28 n5 n19 n20 n8 n68 n44 n29 n17 n67 n13 n14 n27 n26 n18	698 – 716 MHz 699 – 716 MHz 703 – 748 MHz 824 – 849 MHz 830 – 845 MHz 832 – 862 MHz 880 – 915 MHz 698 – 728 MHz 703 – 803 MHz N/A 704 – 716 MHz N/A 777 – 787 MHz 788 – 798 MHz 807 – 824 MHz 814 – 849 MHz 815 – 830 MHz	728 – 746 MHz 729 – 746 MHz 758 – 803 MHz 869 – 894 MHz 875 – 890 MHz 791– 821 MHz 925 – 960 MHz 753 – 783 MHz 703 – 803 MHz 717 – 728 MHz 734 – 746 MHz 738 – 758 MHz 746 – 756 MHz 758 – 768 MHz 852 – 869 MHz 859 – 894 MHz 860 – 875 MHz

				n6	830 – 840 MHz	875 – 885 MHz
1427 – 1518 MHz	n51 n76 n75 n74 n50	1427 – 1432 MHz N/A N/A 1427 – 1470 MHz 1432 – 1517 MHz	1427 – 1432 MHz 1427 – 1432 MHz 1432 – 1517 MHz 1475 – 1518 MHz 1432 – 1517 MHz	n51 n76 n75 n74 n50 n32 n11 n45 n21 n24	1427 – 1432 MHz N/A N/A 1427 – 1470 MHz 1432 – 1517 MHz N/A 1427.9 – 1447.9 MHz 1447 – 1467 MHz 1447.9 – 1462.9 MHz 1626.5 – 1660.5 MHz	1427 – 1432 MHz 1427 – 1432 MHz 1432 – 1517 MHz 1475 – 1518 MHz 1432 – 1517 MHz 1452 – 1496 MHz 1475.9 – 1495.9 MHz 1447 – 1467 MHz 495.9 – 1510.9 MHz 1525 – 1559 MHz
1710 – 2025 MHz 2110 – 2200 MHz	n70 n66 n86 n3 n80 n2 n25 n39 n1 n84 n34	1695 – 1710 MHz 1710 – 1780 MHz 1710 – 1780 MHz 1710 – 1785 MHz 1710 – 1785 MHz 1850 – 1910 MHz 1850 – 1915 MHz 1880 – 1920 MHz 1920 – 1980 MHz 1920 – 1980 MHz 2010 – 2025 MHz	1995 – 2020 MHz 2110 – 2200 MHz N/A 1805 – 1880 MHz N/A 1930 – 1990 MHz 1930 – 1995 MHz 1880 – 1920 MHz 2110 – 2170 MHz N/A 2010 – 2025 MHz	n70 n66 n3 n2 n1 n4 n10 n9 n35 n25 n39 n33 n37 n65 n36 n23 n34	1695 – 1710 MHz 1710 – 1780 MHz 1710 – 1785 MHz 1850 – 1910 MHz 1920 – 1980 MHz 1710 – 1755 MHz 1710 – 1770 MHz 1749.9 – 1784.9 MHz 1850 – 1910 MHz 1850 – 1915 MHz 1880 – 1920 MHz 1900 – 1920 MHz 1910 – 1930 MHz 1920 – 2010 MHz 1930 – 1990 MHz 2000 – 2020 MHz 2010 – 2025 MHz	1995 – 2020 MHz 2110 – 2200 MHz 1805 – 1880 MHz 1930 – 1990 MHz 2110 – 2170 MHz 2110 – 2155 MHz 2110 – 2170 MHz 1844.9 – 1879.9 MHz 1850 – 1910 MHz 1930 – 1995 MHz 1880 – 1920 MHz 1900 – 1920 MHz 1910 – 1930 MHz 2110 – 2200 MHz 1930 – 1990 MHz 2180 – 2200 MHz 2010 – 2025 MHz
2300 – 2400 MHz	n40	2300 – 2400 MHz	2300 – 2400 MHz	n40 n30	2300 – 2400 MHz 2305 – 2315 MHz	2300 – 2400 MHz 2350 – 2360 MHz
2500 – 2690 MHz	n41 n7	2496 – 2690 MHz 2500 – 2570 MHz	2496 – 2690 MHz 2620 – 2690 MHz	n41 n7	2496 – 2690 MHz 2500 – 2570 MHz	2496 – 2690 MHz 2620 – 2690 MHz

	n38	2570 – 2620 MHz	2570 – 2620 MHz	n38 n69	2570 – 2620 MHz N/A	2570 – 2620 MHz 2570 – 2570 MHz
3300 – 3400 MHz 3400 – 3600 MHz 3600 – 3700 MHz 4800 – 4990 MHz	n78 n77 n79	3.3 – 3.8 GHz 3.3 – 4.2 GHz 4.4 – 5.0 GHz	3.3 – 3.8 GHz 3.3 – 4.2 GHz 4.4 – 5.0 GHz	n52 n42 n22 n48 / n49 n43 n46 n47	3300 – 3400 MHz 3400 – 3600 MHz 3410 – 3490 MHz 3550 – 3700 MHz 3600 – 3800 MHz 5150 – 5925 MHz 5855 – 5925 MHz	3300 – 3400 MHz 3400 – 3600 MHz 3510 – 3590 MHz 3550 – 3700 MHz 3600 – 3800 MHz 5150 – 5925 MHz 5855 – 5925 MHz
Higher frequency bands are subject of WRC 2019	n258	24.25 – 27.5 GHz	24.25 – 27.5 GHz	-	-	-
	n257	26.5 – 29.5 GHz	26.5 – 29.5 GHz	-	-	-
	n261	27.5 – 28.35 GHz	27.5 – 28.35 GHz	-	-	-
	n260	37 – 40 GHz	37 – 40 GHz	-	-	-
<p>Remark by 3GPP [4], [8], Section 5.2.3.2.8.3</p> <p><i>For NB-IoT, Category NB1 and NB2 are designed to operate in band 1, 2, 3, 4, 5, 8, 11, 12, 13, 17, 18, 19, 20, 21, 25, 26, 28, 31, 41, 66, 70, 71, 72 and 74 in the above table. See more details in [12] sub-clause 5.5F.</i></p> <p><i>For eMTC, UE category M1 and M2 is designed to operate in band 1, 2, 3, 4, 5, 7, 8, 11, 12, 13, 14, 18, 19, 20, 21, 25, 26, 27, 28, 31, 39, 40, 41, 66, 71, 72 and 74 in the above table. See more details in [12] sub-clause 5.5E.</i></p> <p><i>For V2X communication, the bands can be found in [12] sub-clause 5.5G.</i></p>						

TABLE 136

Characteristics template for 5G NR RIT of “5G” (Release 15 and beyond)

ITU-R [2] [MHz]	<u>For 5G NR component RIT:</u> [4], [8], Section 5.2.3.2.8.3 <i>The following frequency bands will be supported, in accordance with spectrum requirements defined by Report ITU-R M.2411-0. Introduction of other ITU-R IMT identified bands are not precluded in the future. 3GPP technologies are also defined as appropriate to operate in other frequency arrangements and bands.</i>		
	Band number	UL operating band	DL operating band
450 – 470 MHz	-	-	-
470 – 698 MHz	n71	663 – 698 MHz	617 – 652 MHz
694/698 – 960 MHz	n12	699 – 716 MHz	729 – 746 MHz
	n28	703 – 748 MHz	758 – 803 MHz
	n83	703 – 748 MHz	N/A
	n5	824 – 849 MHz	869 – 894 MHz
	n20	832 – 862 MHz	791– 821 MHz
	n82	832 – 862 MHz	N/A
	n8	880 – 915 MHz	925 – 960 MHz
	n81	880 – 915 MHz	N/A
1427 – 1518 MHz	n51	1427 – 1432 MHz	1427 – 1432 MHz
	n76	N/A	1427 – 1432 MHz
	n75	N/A	1432 – 1517 MHz
	n74	1427–1470 MHz	1475 – 1518 MHz
	n50	1432 – 1517 MHz	1432 – 1517 MHz
1710 – 2025 MHz 2110 – 2200 MHz	n70	1695 – 1710 MHz	1995– 2020 MHz
	n66	1710 – 1780 MHz	2110 – 2200 MHz
	n86	1710 – 1780 MHz	N/A
	n3	1710 – 1785 MHz	1805 – 1880 MHz
	n80	1710 – 1785 MHz	N/A
	n2	1850 – 1910 MHz	1930 – 1990 MHz
	n25	1850 – 1915 MHz	1930 – 1995 MHz
	n39	1880 – 1920 MHz	1880 – 1920 MHz
	n1	1920 – 1980 MHz	2110 – 2170 MHz
	n84	1920 – 1980 MHz	N/A
	n34	2010 – 2025 MHz	2010 – 2025 MHz
2300 – 2400 MHz	n40	2300 – 2400 MHz	2300 – 2400 MHz
2500 – 2690 MHz	n41	2496 – 2690 MHz	2496 – 2690 MHz
	n7	2500 – 2570 MHz	2620 – 2690 MHz
	n38	2570 – 2620 MHz	2570 – 2620 MHz
3300 – 3400 MHz	n78	3.3 – 3.8 GHz	3.3 – 3.8 GHz
3400 – 3600 MHz	n77	3.3 – 4.2 GHz	3.3 – 4.2 GHz
3600 – 3700 MHz	n79	4.4 – 5.0 GHz	4.4 – 5.0 GHz
4800 – 4990 MHz			
Higher frequency bands are subject of WRC 2019	n258	24.25 – 27.5 GHz	24.25 – 27.5 GHz
	n257	26.5 – 29.5 GHz	26.5 – 29.5 GHz
	n261	27.5 – 28.35 GHz	27.5 – 28.35 GHz
	n260	37 – 40 GHz	37 – 40 GHz

The combination of the 3GPP submissions on

- SRIT of “5G” (Release 15 and beyond) including NR component RIT and LTE component RIT and
- NR RIT of “5G” (Release 15 and beyond)

is supporting all frequency bands, which are identified for IMT in the ITU Radio Regulations by WARC-92, WRC-2000, WRC-07, WRC-12 and WRC-15.

In addition, the 3GPP submissions are also including higher frequency bands to support the different usage scenarios with a requirement of several hundred MHz up to at least 1 GHz bandwidth corresponding wider and contiguous spectrum ability (c.f. Section 14 on Bandwidth).

The 3GPP submission is fulfilling the minimum requirements according to [2].

II.5.17 Analysis of submitted link budgets

In Report ITU-R M.2133 Section 4.2.3.3, link budget templates are given.

For a given deployment scenario many of the parameter values called out in the link budget templates are given in or are given constraints in Report ITU-R M.2135, § 8. The corresponding parameter entries in the link budget templates follow those sets of values or constraints.

The parameter entries for which there is no guidance in the template should be provided by the proponent. There is no specific requirement associated with how these input parameters have been chosen by the proponent. Furthermore, there is no specific requirement associated with the *results* of the link budget calculations.

In that sense, the link budgets are only informative, but they should be filled in and calculated correctly.

For each of the FDD RIT and TDD RIT, the proponent has supplied link budgets for the LoS and NLOS propagation case (and in the microcellular case also the Outdoor-to-Indoor propagation case) for all mandatory scenarios for all four test environments. For the base coverage urban test environment also link budgets for the optional suburban macro-cell deployment are given.

In a note after each link budget, the proponent states that *“it was necessary to provide separate values for the data channel and the control channel in the following entries: cell area reliability, items 15, 16, 17, 18 and 25 for the reason that the control channel link budget is based on a set of different parameters from those for the data channel, e.g. the bandwidth, cell area reliability, receiver interference density, shadow fading margin, etc.”*

This is a more detailed approach than what Report ITU-R M.2133 requires and provides more information on the balance between control and data link budgets.

As a conclusion, 5G Infrastructure Association finds that the proponent has supplied all required information for both the TDD and FDD RIT in all test environments. Furthermore, it has been verified that all these link budgets are filled in and that the calculations has been performed correctly.

II.6 Questions and feedback to WP 5D and/or the proponents or other IEGs

The minimum requirements on Dense Urban for 30 GHz cannot be realized due to a too high path loss.

II.7 In the interim report, kindly provide the proposed next steps towards the final report to be sent to WP 5D for the February 2020 meeting

Some aspects of the system evaluation are still under preparation and will be provided in the final Evaluation Report:

- Link budget calculation are work in progress.
- User Plane Latency evaluation is work in progress.
- Control Plane Latency for the LTE component is work in progress.
- Mobility: Further details will be provided in the final Evaluation Report.
- Support of Wide Range of Services can only be evaluated after all other characteristics have been evaluated.

The 5G Infrastructure Association Evaluation Group will finalize the missing evaluation characteristics and results before submitting the final Evaluation Report in February 2020.

Potentially, detailed interactions with other evaluation groups will take place after the ITU-R Evaluation Workshop on December 10 and 11, 2019.

PART III

Conclusion

III.1 Completeness of submission

5G Infrastructure Association finds that the submission in [4] to [8] and are ‘complete’ according to [2].

III.2 Compliance with requirements

These are the main conclusions on the 5G Infrastructure Association evaluation of the evaluated proposal. In Table 137 below, it is shown whether or not 5G Infrastructure Association has confirmed the proponent’s claims relating to IMT-2020 requirements.

The phrase ‘Requirements fulfilled’ in the tables below indicates that 5G Infrastructure Association Evaluation Group assessment confirms the associated claim from the proponent that the requirement is fulfilled.

In Section III-2.1 the detailed compliance templates are summarized.

III.2.1 Overall compliance

TABLE 137

5G Infrastructure Association assessment of compliance with requirements

Characteristic for evaluation	RIT NR: 5G IA assessment	SRIT LTE: 5G IA assessment	Section
Peak data rate	Requirements fulfilled	Requirements fulfilled	Part II.5.1
Peak spectral efficiency	Requirements fulfilled	Requirements fulfilled	Part II.5.2
User experienced data rate	Requirements fulfilled except II.5.3.2.2 for dense urban TDD at 30 GHz	Not applicable According to [3], Section 7, the minimum requirements should be fulfilled by a RIT or jointly by different components of a SRIT. Hence, in the case of 3GPP's proposal of both a pure 5G-NR RIT and an SRIT, where 5G-NR is augmented by a LTE component, it is sufficient to only verify, that the 5G RIT meets the minimum performance requirements. Accordingly, the evaluation for this and related KPIs analyzed by means of system-level simulation is restricted to 5G-NR RIT only.	Part II.5.3
5 th percentile user spectral efficiency	Requirements fulfilled except II.5.4.2.2.2 for dense urban at 30 GHz	Not applicable According to [3], Section 7, the minimum requirements should be fulfilled by a RIT or jointly by different components of a SRIT. Hence, in the case of 3GPP's proposal of both a pure 5G-NR RIT and an SRIT, where 5G-NR is augmented by a LTE component, it is sufficient to only verify, that the 5G RIT meets the minimum performance requirements. Accordingly, the evaluation for this and related KPIs analyzed by means of system-level simulation is restricted to 5G-NR RIT only.	Part II.5.4
Average spectral efficiency	Requirements fulfilled except II.5.5.2.2.2 for dense urban at 30 GHz	Not applicable According to [3], Section 7, the minimum requirements should be fulfilled by a RIT or jointly by different components of a SRIT. Hence, in the case of 3GPP's proposal of both a pure 5G-NR RIT and an SRIT, where 5G-NR is augmented by a LTE component, it is sufficient to only verify, that the 5G RIT meets the minimum performance requirements. Accordingly, the evaluation	Part II.5.5

		for this and related KPIs analyzed by means of system-level simulation is restricted to 5G-NR RIT only.	
Area traffic capacity	Requirements fulfilled	Not applicable According to [3], Section 7, the minimum requirements should be fulfilled by a RIT or jointly by different components of a SRIT. Hence, in the case of 3GPP's proposal of both a pure 5G-NR RIT and an SRIT, where 5G-NR is augmented by a LTE component, it is sufficient to only verify, that the 5G RIT meets the minimum performance requirements. Accordingly, the evaluation for this and related KPIs analyzed by means of system-level simulation is restricted to 5G-NR RIT only.	Part II.5.6
User plane latency	Requirements fulfilled	Requirements fulfilled	Part II.5.7
Control plane latency	Requirements fulfilled	Requirements fulfilled	Part II.5.8
Connection density	Requirements fulfilled	Not applicable According to [3], Section 7, the minimum requirements should be fulfilled by a RIT or jointly by different components of a SRIT. Hence, in the case of 3GPP's proposal of both a pure 5G-NR RIT and an SRIT, where 5G-NR is augmented by a LTE component, it is sufficient to only verify, that the 5G RIT meets the minimum performance requirements. Accordingly, the evaluation for this and related KPIs analyzed by means of system-level simulation is restricted to 5G-NR RIT only.	Part II.5.9
Energy efficiency	Requirements fulfilled	Requirements fulfilled	Part II.5.10
Reliability	Requirements fulfilled	Requirements fulfilled	Part II.5.11
Mobility	Requirements fulfilled	Requirements fulfilled	Part II.5.12
Mobility interruption time	Requirements fulfilled	Requirements fulfilled	Part II.5.13
Bandwidth	Requirements fulfilled	Requirements fulfilled	Part II.5.14
Support of wide range of services	Requirements fulfilled	Requirements fulfilled	Part II.5.15
Supported spectrum band(s)/range(s)	Requirements fulfilled	Requirements fulfilled	Part II.5.16

It should be noted that the analysis behind the analytical and inspection results is not limited by properties of the test environment; hence all these conclusions are valid for all test environments.

III.2.2 Detailed compliance templates

III.2.2.1 Compliance template for services⁴

	Service capability requirements	Evaluator's comments
5.2.4.1.1	<p>Support for wide range of services</p> <p>Is the proposal able to support a range of services across different usage scenarios (eMBB, URLLC, and mMTC)? X YES / <input type="checkbox"/> NO</p> <p>Specify which usage scenarios (eMBB, URLLC, and mMTC) the candidate RIT or candidate SRIT can support.⁽¹⁾</p>	All evaluation characteristics are fulfilling the ITU-R minimum requirements and therefore a wide range of services is supported.

⁽¹⁾ Refer to the process requirements in IMT-2020/2.

III.2.2.2 Compliance template for spectrum³

	Spectrum capability requirements
5.2.4.2.1	<p>Frequency bands identified for IMT</p> <p>Is the proposal able to utilize at least one frequency band identified for IMT in the ITU Radio Regulations? X YES / <input type="checkbox"/> NO</p> <p>Specify in which band(s) the candidate RIT or candidate SRIT can be deployed.</p>
5.2.4.2.2	<p>Higher Frequency range/band(s)</p> <p>Is the proposal able to utilize the higher frequency range/band(s) above 24.25 GHz? X YES / <input type="checkbox"/> NO</p> <p>Specify in which band(s) the candidate RIT or candidate SRIT can be deployed. Details are provided in Section II.5.16. NOTE 1 – In the case of the candidate SRIT, at least one of the component RITs need to fulfil this requirement.</p>

III.2.2.3 Compliance template for technical performance³

Minimum technical performance requirements item (5.2.4.3.x), units, and Report ITU-R M.2410-0 section reference ⁽¹⁾	Category			Required value	Value ⁽²⁾	Requirement met?	Comments ⁽³⁾
	Usage scenario	Test environment	Downlink or uplink				
5.2.4.3.1 Peak data rate (Gbit/s) (4.1)	eMBB	Not applicable	Downlink	20		X Yes <input type="checkbox"/> No	c.f. II.5.1
			Uplink	10		X Yes <input type="checkbox"/> No	

⁴ If a proponent determines that a specific question does not apply, the proponent should indicate that this is the case and provide a rationale for why it does not apply.

Minimum technical performance requirements item (5.2.4.3.x), units, and Report ITU-R M.2410-0 section reference ⁽¹⁾	Category			Required value	Value ⁽²⁾	Requirement met?	Comments ⁽³⁾
	Usage scenario	Test environment	Downlink or uplink				
5.2.4.3.2 Peak spectral efficiency (bit/s/Hz) (4.2)	eMBB	Not applicable	Downlink	30		X Yes <input type="checkbox"/> No	c.f. II.5.2
			Uplink	15		X Yes <input type="checkbox"/> No	
5.2.4.3.3 User experienced data rate (Mbit/s) (4.3)	eMBB	Dense Urban – eMBB	Downlink	100		X Yes <input type="checkbox"/> No	c.f. II.5.3 Not fulfilled in config-B, c.f. explanation
			Uplink	50		X Yes <input type="checkbox"/> No	
5.2.4.3.4 5 th percentile user spectral efficiency (bit/s/Hz) (4.4)	eMBB	Indoor Hotspot – eMBB	Downlink	0.3		X Yes <input type="checkbox"/> No	c.f. II.5.4
			Uplink	0.21		X Yes <input type="checkbox"/> No	
	eMBB	Dense Urban – eMBB	Downlink	0.225		X Yes <input type="checkbox"/> No	c.f. II.5.4 Not fulfilled in config-B, c.f. explanation
			Uplink	0.15		X Yes <input type="checkbox"/> No	
	eMBB	Rural – eMBB	Downlink	0.12		X Yes <input type="checkbox"/> No	c.f. II.5.4
			Uplink	0.045		X Yes <input type="checkbox"/> No	
5.2.4.3.5 Average spectral efficiency (bit/s/Hz/ TRxP) (4.5)	eMBB	Indoor Hotspot – eMBB	Downlink	9		X Yes <input type="checkbox"/> No	c.f. II.5.5
			Uplink	6.75		X Yes <input type="checkbox"/> No	
	eMBB	Dense Urban – eMBB	Downlink	7.8		X Yes <input type="checkbox"/> No	c.f. E-II.5 Not fulfilled in Config-B, c.f. explanation
			Uplink	5.4		X Yes <input type="checkbox"/> No	
	eMBB	Rural – eMBB	Downlink	3.3		X Yes <input type="checkbox"/> No	c.f. E-II.5
			Uplink				

Minimum technical performance requirements item (5.2.4.3.x), units, and Report ITU-R M.2410-0 section reference ⁽¹⁾	Category			Required value	Value ⁽²⁾	Requirement met?	Comments ⁽³⁾
	Usage scenario	Test environment	Downlink or uplink				
				Uplink	1.6		X Yes <input type="checkbox"/> No
5.2.4.3.6 Area traffic capacity (Mbit/s/m ²) (4.6)	eMBB	Indoor-Hotspot – eMBB	Downlink	10		X Yes <input type="checkbox"/> No	c.f. E-II.6
5.2.4.3.7 User plane latency (ms) (4.7.1)	eMBB	Not applicable	Uplink and Downlink	4		X Yes <input type="checkbox"/> No	c.f. E-II.7
	URLLC	Not applicable	Uplink and Downlink	1		X Yes <input type="checkbox"/> No	c.f. E-II.7
5.2.4.3.8 Control plane latency (ms) (4.7.2)	eMBB	Not applicable	Not applicable	20		X Yes <input type="checkbox"/> No	c.f. E-II.8
	URLLC	Not applicable	Not applicable	20		X Yes <input type="checkbox"/> No	c.f. E-II.8
5.2.4.3.9 Connection density (devices/km ²) (4.8)	mMTC	Urban Macro – mMTC	Uplink	1 000 000		X Yes <input type="checkbox"/> No	c.f. E-II.9
5.2.4.3.10 Energy efficiency (4.9)	eMBB	Not applicable	Not applicable	Capability to support a high sleep ratio and long sleep duration		X Yes <input type="checkbox"/> No	c.f. E-II.10
5.2.4.3.11 Reliability (4.10)	URLLC	Urban Macro – URLLC	Uplink or Downlink	1-10 ⁻⁵ success probability of transmitting a layer 2 PDU (protocol data unit) of size 32 bytes within 1 ms in channel quality of coverage edge		X Yes <input type="checkbox"/> No	c.f. E-II.11
5.2.4.3.12 Mobility classes (4.11)	eMBB	Indoor Hotspot – eMBB	Uplink	Stationary, Pedestrian		X Yes <input type="checkbox"/> No	c.f. E-II.12
	eMBB	Dense Urban – eMBB	Uplink	Stationary, Pedestrian, Vehicular (up to 30 km/h)		X Yes <input type="checkbox"/> No	c.f. E-II.12
	eMBB	Rural – eMBB	Uplink	Pedestrian, Vehicular, High speed vehicular		X Yes <input type="checkbox"/> No	c.f. E-II.12
5.2.4.3.13 Mobility	eMBB	Indoor Hotspot – eMBB	Uplink	1.5 (10 km/h)		X Yes <input type="checkbox"/> No	c.f. E-II.13

Minimum technical performance requirements item (5.2.4.3.x), units, and Report ITU-R M.2410-0 section reference ⁽¹⁾	Category			Required value	Value ⁽²⁾	Requirement met?	Comments ⁽³⁾
	Usage scenario	Test environment	Downlink or uplink				
Traffic channel link data rates (bit/s/Hz) (4.11)	eMBB	Dense Urban – eMBB	Uplink	1.12 (30 km/h)		X Yes <input type="checkbox"/> No	c.f. E-II.13
	eMBB	Rural – eMBB	Uplink	0.8 (120 km/h)		X Yes <input type="checkbox"/> No	c.f. E-II.13
				0.45 (500 km/h)		X Yes <input type="checkbox"/> No	c.f. E-II.13
5.2.4.3.14 Mobility interruption time (ms) (4.12)	eMBB and URLLC	Not applicable	Not applicable	0		X Yes <input type="checkbox"/> No	c.f. E-II.14
5.2.4.3.15 Bandwidth and Scalability (4.13)	Not applicable	Not applicable	Not applicable	At least 100 MHz		X Yes <input type="checkbox"/> No	c.f. II.5.16
				Up to 1 GHz		X Yes <input type="checkbox"/> No	c.f. II.5.16
				Support of multiple different bandwidth values ⁽⁴⁾		X Yes <input type="checkbox"/> No	c.f. II.5.16

⁽¹⁾ As defined in Report ITU-R M.2410-0.

⁽²⁾ According to the evaluation methodology specified in Report ITU-R M.2412-0.

⁽³⁾ Proponents should report their selected evaluation methodology of the Connection density, the channel model variant used, and evaluation configuration(s) with their exact values (e.g. antenna element number, bandwidth, etc.) per test environment, and could provide other relevant information as well. For details, refer to Report ITU-R M.2412-0, in particular, § 7.1.3 for the evaluation methodologies, § 8.4 for the evaluation configurations per each test environment, and Annex 1 on the channel model variants.

⁽⁴⁾ Refer to § 7.3.1 of Report ITU-R M.2412-0.

III.3 Number of test environments meeting all IMT-2020 requirements

This section is a place holder for the final report since no conclusions can be drawn until all relevant simulation-based evaluations have been made.

III.4 Conclusion of link budget analysis

Link budget calculations are work in progress Details will be provided in the final Evaluation Report. 5G Infrastructure Association concludes that the proponent has provided the required information relating to link budgets for all four test environments for both the TDD RIT and the FDD RIT.

ANNEX A

Detailed assumptions on DL and UL peak data rate and peak spectral efficiency calculations for 5G NR and LTE

5G NR Downlink

Parameters	Downlink Configuration			Details
	FDD FR1	TDD FR1	TDD FR2	
Total number of aggregated carriers J	16			Maximum allowed value
$\alpha_{DL}^{(j)}$	1	0.7643	0.7643	Note 1
Max. number of layers $\nu_{Layers}^{(j)}$	8 (FR1), 6 (FR2)			Note 2
Highest modulation order $Q_m^{(j)}$	8			256 QAM
Scaling factor of modulation $f^{(j)}$	1			No capability mismatch between baseband and RF.
Max. coding rate R_{max}	984/1024 = 0.9258			Maximum CR
μ	0,1,2,3			According to [10]
T_s^μ	$T_s^\mu = \frac{10^{-3}}{14 \cdot 2^\mu}$			Depending on the numerology.
$N_{PRB}^{BW(j),\mu}$	- 270 for BW 50 MHz, SCS 15 kHz - 273 for BW 100 MHz, SCS 30 kHz - 135 for BW 100 MHz, SCS 60 kHz		- 264 for BW 200 MHz, SCS 60 kHz - 264 for BW 400 MHz, SCS 120 kHz	Depending on the available bandwidth [9] and the numerology.
$OH^{(j)}$	- 0.1037 for BW 50 MHz, SCS 15 kHz - 0.1036 for BW 100 MHz, SCS 30 kHz - 0.1076 for BW 100 MHz, SCS 60 kHz	- 0.1192 for BW 50 MHz, SCS 15 kHz - 0.1193 for BW 100 MHz, SCS 30 kHz - 0.1235 for BW 100 MHz, SCS 60 kHz	- 0.1855 for BW 200 MHz, SCS 60 kHz - 0.1827 for BW 400 MHz, SCS 120 kHz	Note 3
<p>Note 1: FDD/TDD Frame Structure</p> <ul style="list-style-type: none"> For FDD DL, all subframes, slots and OFDM symbols in the 5G NR frame are assigned to DL transmissions. For TDD DL, frame structure: DDSUDDSU (6D: Downlink, 2U: Uplink, 2S: Mixed Downlink and Uplink) and SFI = 31 with a slot structure allocating 14 OFDM symbols as: 11 DL, 1 GP and 2 UL. Half of the GP symbols are considered as DL resources. <p>Note 2: Maximum number of layers</p> <ul style="list-style-type: none"> In FR1, the maximum number of layers is equal to the maximum value allowed for DL, i.e. 8 layers. 				

- In FR2, the maximum number of layers is set to 6 since 8 layers cannot be configured due to complexity issues related to the operation in high frequency bands.

Note 3: Overhead Assumptions

- For FDD FR1:
 - **Total REs:** 10 subframes with 14 OFDM symbols per slot assigned to DL transmissions.
 - **SS/PBCH:** 1 block transmitted each 20 slots. Each block is composed of 240 subcarriers x 4 OFDM symbols.
 - **PDCCH:** 1 CORESET per slot with 2 CCEs (12 RB) in all subframes with DL content (All the subframes).
 - **PDSCH:**
 - DMRS: 16 RE/RB/slot in all RBs in all slots in all subframes.
 - CSI-RS NZP: 8 RE/RB/slot in all RBs each 20 slots.
 - CSI – IM: 4 RE/RB/slot in all RBs each 20 slots.
 - CSI-RS (TRS): 12 RE/RB/slot in 52 RBs each 20 slots.
- For TDD FR1:
 - **Total REs:** 6 DL subframes with 14 OFDM symbols per slot, 1 Mixed subframe with 12 OFDM symbols (11 DL and 1 GP) per slot and 1 Mixed subframe with 12 OFDM symbols (11 DL) assigned to DL transmissions.
 - **GP:** 1 OFDM symbol in each slot in 1 Mixed UL/DL subframe.
 - **SS/PBCH:** 1 block transmitted each 20 slots. Each block is composed of 240 subcarriers x 4 OFDM symbols.
 - **PDCCH:** 1 CORESET per slot with 2 CCEs (12 RB) in all subframes with DL content (8 out of 10 subframes).
 - **PDSCH:**
 - DMRS: 16 RE/RB/slot in all RBs in all slots in 8 out of 10 subframes.
 - CSI-RS NZP: 8 RE/RB/slot in all RBs each 20 slots.
 - CSI – IM: 4 RE/RB/slot in all RBs each 20 slots.
 - CSI-RS (TRS): 12 RE/RB/slot in 52 RBs each 20 slots.
- For TDD FR2:
 - **Total REs:** 6 DL subframes with 14 OFDM symbols per slot, 1 Mixed subframe with 12 OFDM symbols (11 DL and 1 GP) per slot and 1 Mixed subframe with 12 OFDM symbols (11 DL) assigned to DL transmissions.
 - **GP:** 1 OFDM symbol in each slot in 1 Mixed UL/DL subframe.
 - **SS/PBCH:** 8 blocks transmitted each 20 slots. Each block 240 subcarriers x 4 OFDM symbols.
 - **PDCCH:** 1 CORESET per slot with 4 CCEs (24 RB) in all subframes with DL content (8 out of 10 subframes).
 - **PDSCH:**
 - DMRS: 12 RE/RB/slot in all RBs in all slots in 8 out of 10 subframes.
 - CSI-RS NZP: 8 RE/RB/slot in all RBs each 20 slots.
 - CSI – IM: 4 RE/RB/slot in all RBs each 20 slots.
 - CSI-RS (TRS): 12 RE/RB/slot in 52 RBs each 20 slots.
 - PT-RS: 4 RB in 1 OFDM symbol in all slots in 8 out of 10 subframes.

5G NR Uplink

Parameters	Uplink Configuration			Details
	FDD FR1	TDD FR1	TDD FR2	
Total number of aggregated carriers J	16			Maximum value allowed
$\alpha_{UL}^{(j)}$	1	0.6375	0.6375	Note 1
Max. number of layers $v_{Layers}^{(j)}$	4			Maximum value allowed for UL
Highest modulation order $Q_m^{(j)}$	8			256 QAM
Scaling factor of modulation $f^{(j)}$	1			No capability mismatch between baseband and RF.

Max. coding rate R_{max}	984/1024 = 0.9258		Maximum CR
μ	0,1,2,3		According to [10]
T_s^μ	$T_s^\mu = \frac{10^{-3}}{14 \cdot 2^\mu}$		Depending on the numerology.
$N_{PRB}^{BW(j),\mu}$	- 270 for BW 50 MHz, SCS 15 kHz - 273 for BW 100 MHz, SCS 30 kHz - 135 for BW 100 MHz, SCS 60 kHz	- 264 for BW 200 MHz, SCS 60 kHz - 264 for BW 400 MHz, SCS 120 kHz	Depending on the available bandwidth [9] and the numerology.
$OH^{(j)}$	- 0.0834 for BW 50 MHz, SCS 15 kHz - 0.0815 for BW 100 MHz, SCS 30 kHz - 0.0826 for BW 100 MHz, SCS 60 kHz	- 0.1194 for BW 50 MHz, SCS 15 kHz - 0.1163 for BW 100 MHz, SCS 30 kHz - 0.1174 for BW 100 MHz, SCS 60 kHz	- 0.1163 for BW 200 MHz, SCS 60 kHz - 0.1155 for BW 400 MHz, SCS 120 kHz Note 2

Note 1: FDD/TDD Frame Structure

- For FDD UL, all subframes, slots and OFDM symbols in the 5G NR frame are assigned to UL transmissions.
- For TDD UL, frame structure: UUUSDUUUSD (6U: Uplink, 2D: Downlink, 2S: Mixed Downlink and Uplink) and SFI = 31 with a slot structure allocating 14 OFDM symbols as: 11 DL, 1 GP and 2 UL.

Note 2: Overhead Assumptions

- For FDD FR1:
 - **Total REs:** 10 subframes where all slots convey 14 OFDM symbols for UL transmissions.
 - **PRACH:** Preamble #71, 12 RB in 6 OFDM symbols in each slot in 2 out of 10 subframes.
 - **PUCCH:** Format 3 to convey CSI, HARQ ACK/NACK and SR. 2 RB in 4 OFDM Symbols in each slot in all subframes.
 - **PUSCH:**
 - DMRS: 12 RE/RB/slot in all RBs in all slots in all subframes.
 - SRS: 12 RE/RB in all RBs of 1 OFDM symbol each 10 slots.
- For TDD FR1:
 - **Total REs:** 6 UL subframes with 14 OFDM symbols per slot, 1 Mixed subframes with 2 OFDM symbols per slot assigned to UL transmissions, and 1 Mixed subframe with 3 OFDM symbols per slot assigned to UL transmissions.
 - **PRACH:** Preamble #71, 12 RB in 6 OFDM symbols in 2 out of 10 subframes.
 - **PUCCH:** Format 3 to convey CSI, HARQ ACK/NACK and SR. 2 RB in 2 OFDM symbols in each slot in 6 out of 10 subframes.
 - **PUSCH:**
 - DMRS: 12 RE/RB/slot in all RBs in all slots in all subframes.
 - SRS: 12 RE/RB in all RBs of 1 OFDM symbol each 10 slots.
- For TDD FR2:
 - **Total REs:** 6 UL subframes with 14 OFDM symbols per slot, 1 Mixed subframes with 2 OFDM symbols per slot assigned to UL transmissions, and 1 Mixed subframe with 3 OFDM symbols per slot assigned to UL transmissions.
 - **PRACH:** Preamble #71, 12 RB in 6 OFDM symbols in 2 out of 10 subframes.
 - **PUCCH:** Format 3 to convey CSI, HARQ ACK/NACK and SR. 2 RB in 2 OFDM symbols in each slot in 6 out of 10 subframes.
 - **PUSCH:**
 - DMRS: 12 RE/RB/slot in all RBs in all slots in 8 out of 10 subframes.
 - SRS: 12 RE/RB in all RBs of 1 OFDM symbol each 10 slots.
 - PT-RS: 4 RB in 1 OFDM symbol in all slots in 8 out of 10 subframes.

LTE Downlink

Parameters	Downlink Configuration		Details
	FDD	TDD	
Total number of aggregated carriers J	32		Maximum allowed value
$\alpha_{DL}^{(j)}$	1	0.7429	Note 1
Max. number of layers $\nu_{Layers}^{(j)}$	8		Maximum value allowed for DL
Highest modulation order $Q_m^{(j)}$	8, 10		256 QAM 1024 QAM
Scaling factor of modulation $f^{(j)}$	1		No capability mismatch between baseband and RF.
Max. coding rate R_{max}	$R_{max} \leq 0.93$		Depending on the maximum Transport block size (TBS) defined in [10] and the number of useful data bits.
Subcarrier Spacing (kHz)	15		According to [10] for unicast subframes
T_s^μ	$T_s^\mu = \frac{10^{-3}}{14}$		OFDM symbol duration
$N_{PRB}^{BW(j),\mu}$	100 for BW 20 MHz, SCS 15 kHz		Depending on the available bandwidth and the subcarrier spacing [10]
$OH^{(j)}$	0.327 for BW 20 MHz, SCS 15 kHz	0.304 for BW 20 MHz, SCS 15 kHz	Note 2
<p>Note 1: FDD/TDD Frame Structure</p> <ul style="list-style-type: none"> For FDD DL, all subframes, slots and OFDM symbols in the LTE frame are assigned to DL transmissions. For TDD DL, frame structure: DSUDDDSUDD (6D: Downlink, 2U: Uplink, 2S: Mixed Downlink and Uplink) and TDD Special subframe configuration of 10 OFDM symbols for DL, 1 for UL and 3 for GP. <p>Note 2: Overhead Assumptions</p> <ul style="list-style-type: none"> For FDD: <ul style="list-style-type: none"> Total REs: 10 subframes with 14 OFDM symbols per subframe assigned to DL transmissions. PBCH: 1 transmitted each 20 slots. Each block is composed of 240 REs excluding CRS. PSS/SSS + Null Cells: 288 REs each 10 ms. PDCCH: 1 or 2 full OFDM symbols in all subframes with DL content. PDSCH: <ul style="list-style-type: none"> CRS: 8 RE/RB/subframe in all RBs in all subframes. DMRS: 24 RE/RB/subframe in all RBs in all subframes. CSI-RS: 8 RE/RB in all RBs each 20 ms. For TDD: <ul style="list-style-type: none"> Total REs: 6 DL subframes with 14 OFDM symbols and 2 Mixed DL/UL subframes with 13 OFDM symbols assigned to DL or GP transmissions. GP: 3 full OFDM symbols in each slot in 2 Mixed UL/DL subframes in each 5G NR frame. PBCH: 1 transmitted each 20 slots. Each block is composed of 240 REs excluding CRS. PSS/SSS + Null Cells: 288 REs per subframe. Each block is composed of 240 REs excluding CRS. PDCCH: 1 or 2 full OFDM symbols in all subframes with DL and mixed DL/UL content. PDSCH: <ul style="list-style-type: none"> CRS: 4 RE/RB/slot in all RBs in all slots in all subframes. DMRS: 12 RE/RB/subframe in all RBs in all subframes. CSI-RS: 8 RE/RB in all RBs each 20 ms. 			

LTE Uplink

Parameters	Downlink Configuration		Details
	FDD	TDD	
Total number of aggregated carriers J	32		Maximum allowed value
$\alpha_{DL}^{(j)}$	1	0.6143	Note 1
Max. number of layers $\nu_{Layers}^{(j)}$	4		Maximum value allowed for UL
Highest modulation order $Q_m^{(j)}$	8		256QAM
Scaling factor of modulation $f^{(j)}$	1		No capability mismatch between baseband and RF.
Max. coding rate R_{max}	$R_{max} \leq 0.93$		Depending on the maximum Transport block size (TBS) defined in [10] and the number of useful data bits.
Subcarrier Spacing (kHz)	15		According to [10] for unicast subframes
T_s^μ	$T_s^\mu = \frac{10^{-3}}{14}$		OFDM symbol duration
$N_{PRB}^{BW(j),\mu}$	100 for BW 20 MHz, SCS 15 kHz		Depending on the available bandwidth and the subcarrier spacing [10]
$OH^{(j)}$	0.1701 for BW 20 MHz, SCS 15 kHz	0.2472 for BW 20 MHz, SCS 15 kHz	Note 2

Note 1: FDD/TDD Frame Structure

- For FDD UL, all subframes, slots and OFDM symbols in LTE frames are assigned to UL transmission.
- For TDD UL, frame structure: DSUUUDSUUU (2D: Downlink, 6U: Uplink, 2S: Mixed Downlink and Uplink) and TDD Special subframe configuration of 10 OFDM symbols for DL, 1 for UL and 3 for GP.

Note 2: Overhead Assumptions

- For FDD:
 - **Total REs:** 10 subframes with 14 OFDM symbols per subframe assigned to UL transmissions.
 - **PRACH:** 72 REs in 1 subframe each 10 ms
 - **PUCCH:** 336 REs per subframe in all UL subframes.
 - **PUSCH:**
 - DMRS: 2 full OFDM symbols per subframe in all UL subframes
 - SRS: 96 RBs in 1 OFDM symbol in 1 subframe each 10 ms.
- For TDD:
 - **Total REs:** 6 DL subframes with 14 OFDM symbols and 2 Mixed DL/UL subframes with 1 OFDM symbols assigned to UL transmissions.
 - **GP:** 3 OFDM symbols in each slot in 2 Mixed UL/DL subframes in each 5G NR frame.
 - **PRACH:** 72 REs in 1 subframe each 10 ms.
 - **PUCCH:** 336 REs per subframe in all UL and mixed DL/UL subframes.
 - **PUSCH:**
 - DMRS: 2 OFDM per subframe in all UL subframes.
 - SRS: 96 RBs in 1 OFDM symbol in 1 subframe each 10 ms.

ANNEX B

Detailed simulation parameters for system-level simulation-based analysis

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.

Source 1 (TDD: DSUUD, FDD)

Parameters	Values		
	Indoor Hotspot – eMBB	Dense Urban – eMBB	Rural - eMBB
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 $\phi_i = [0]$, Zenith angle $\theta_j = [\pi/2]$	N/A	N/A
Beam set at UE	Configuration B: Azimuth angle $\phi_i = [-\pi/4, \pi/4]$; Zenith angle $\theta_j = [\pi/4, 3\pi/4]$	Configuration B: Azimuth angle $\phi_i = [-\pi/4, \pi/4]$; Zenith angle $\theta_j = [\pi/4, 3\pi/4]$	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; Configuration A: Maximum MU layer = 12; Configuration B: Maximum MU layer = 6	MU-MIMO with rank 1-2 adaptation per user; Maximum MU layer = 12	MU-MIMO with rank 1-2 adaptation per user; 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	TDD: SRS based	TDD: SRS based	TDD: SRS based

derivation		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

Source 2 with spectral efficiency evaluation assumption (TDD: DDDSU, FDD)

Parameters	Values		
	Indoor Hotspot – eMBB	Dense Urban – eMBB	Rural - eMBB
Test environment	Indoor Hotspot – eMBB	Dense Urban – eMBB	Rural - eMBB
Evaluation configuration	Configuration A/B	Configuration A	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	DDDSU	DDDSU	DDDSU
Carrier frequency	Configuration A: 4 GHz Configuration B: 30 GHz	4 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: 10 MHz	FDD: 10 MHz
Subcarrier spacing	Configuration A: 15 kHz Configuration B: 60 kHz	15 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);	For 32Tx: 64Tx cross-polarized antennas (M,N,P,Mg,Ng;Mp,Np) = (8,8,2,1,1;2,8)	Configuration A/C: 32Tx cross-polarized antennas (M,N,P,Mg,Ng;Mp,Np) = (8,4,2,1,1;1,4); Configuration B: 164Tx 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	32TXRU: Vertical 2-to-8	Configuration A/C: 8TXRU, Vertical 1-to-8; Configuration B: 32TXRU, Vertical 2-to-8
Number of antenna elements per UE	Configuration A: 4Rx with 0° and 90° polarization Configuration B: 8Rx with 0° and 90° polarization (M,N,P,Mg,Ng; Mp,Np) = (2,4,2,1,2; 1,2)	4Rx with 0° and 90° polarization	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 $\phi_i = [0]$, Zenith angle $\theta_j = [\pi/2]$	N/A	N/A
Beam set at UE	Configuration B: Azimuth angle $\phi_i = [-\pi/4, \pi/4]$; Zenith angle $\theta_j = [\pi/4, 3*\pi/4]$	N/A	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
Downlink scheduling	MU-PF	MU-PF	MU-PF
Downlink MIMO mode	MU-MIMO with rank 1-2 adaptation per user; Configuration A: Maximum MU layer = 12; Configuration B: Maximum MU layer = 6	MU-MIMO with rank 1-2 adaptation per user; Maximum MU layer = 12	MU-MIMO with rank 1-2 adaptation per user; 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	Non-precoded SRS for 4Tx ports; Period: 5 slots; 2 symbols	Non-precoded SRS for 4Tx ports; Period: 5 slots; 2 symbols	Non-precoded SRS for 2Tx/4Tx 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, wideband + subband quantization, 8 PSK)	FDD: NR Type II codebook (4 beams, wideband + subband quantization, 8 PSK)	FDD: NR Type II codebook (4 beams, wideband + subband quantization, 8 PSK)
Downlink Overhead	PDCCH	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)
	CSI-RS	FDD: 32 ports per 5 slots	FDD: 32 ports per 5 slots
			FDD: 8/32 ports for 8Tx/32Tx

		TDD: 32 ports per 5 slots	TDD: 32 ports per 5 slots	TDD: 8/32 ports for 8Tx/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 2 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		$\alpha = 0.6, P_0 = -60$ dBm	$\alpha = 0.9, P_0 = -86$ 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
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

Source 1 additional parameters for single-band multi-layer configuration in Dense Urban C for user experienced data rate

For evaluation of user experienced data rate the following parameters pertaining to micro-layer deployment and UE drop model apply on top of those specified above for Dense Urban Configuration A. Where parameters are not specified, the same settings as for the macro-layer apply.

Parameters	Values
Micro TRxP drop model	u.i.i.d. with minimum distance of 40m between any pair of TRxPs.
UE drop model	10 UEs per TRxP. Macro: u.i.i.d. over macro cell area Micro: u.i.i.d. within radius of 20m around micro cell.
Transmit power per TRxP	33 dBm
TRxP number per site	1
Electronic tilt	102° in LCS

Source 2 with user experienced data evaluation assumption

For evaluation configuration A, the evaluation assumption is the same as that of spectral efficiency evaluation in Dense Urban – eMBB test environment. The following assumption is applied in the evaluation configuration C (multi-layer) for user experienced data evaluation.

Parameters	Values	
	Dense Urban – eMBB	Dense Urban – eMBB
Test environment		
Evaluation configuration	Configuration A	Configuration C
Channel model	UMa_B	UMa_B
ISD	200m	200m
Frame structure	UUUUU (FDD)	DDDSU
Carrier frequency	4 GHz	4 GHz
Simulation bandwidth	10 MHz	80 MHz
Subcarrier spacing	15 kHz	60 kHz
Number of symbols per slot	14	14
Number of antenna elements per TRxP	For 32Tx: 64Tx cross-polarized antennas (M,N,P,Mg,Ng;Mp,Np) = (8,8,2,1,1;2,8)	For 32Tx: 128Tx cross-polarized antennas (M,N,P,Mg,Ng;Mp,Np) = (4,8,2,2,2; 1,4)
Number of TXRU per TRxP	32TXRU: Vertical 2-to-8	32TXRU Vertical 1-to-4 and horizontal 1 to 2
Number of antenna elements per UE	4Rx with 0° and 90° polarization	8Rx with 0° and 90° polarization (M,N,P,Mg,Ng; Mp,Np) = (2,4,2,1,2; 1,2)
Transmit power per TRxP	41 dBm	40 dBm
TRxP number per site	3	3
Mechanic tilt	90° in GCS (pointing to the horizontal direction)	90° in GCS (pointing to the horizontal direction)

Electronic tilt	105° in LCS	(According to Zenith angle in "Beam set at TRxP")	
Beam set at TRxP	N/A	For direction of TRxP analog beam steering (in LCS): Azimuth angle $\phi_i = [-\pi/4, \pi/4]$ Zenith angle $\theta_j = 7*\pi/12$	
Beam set at UE	N/A	For direction of UE analog beam steering (in LCS): Azimuth angle $\phi_i = [-\pi/4, \pi/4]$ Zenith angle $\theta_j = [\pi/4, 3*\pi/4]$;	
UT attachment	Based on RSRP (Eq. (8.1-1) in TR 36.873) from port 0	B Maximizing RSRP with best analog beam pair, where the digital beamforming is not considered	
Guard band ratio	6.4% for 15 kHz SCS (for 10 MHz)	5.5% for 60 kHz SCS (for 80 MHz)	
BS receiver type	MMSE-IRC	MMSE-IRC	
SRS transmission	Non-precoded SRS for 4Tx ports; Period: 5 slots; 2 symbols	Non-precoded SRS for 2Tx ports; Period: 5 slots; 2 symbols	
Channel estimation	Non-ideal	Non-ideal	
Waveform	OFDM	OFDM	
UE power class	23 dBm	23 dBm	
Uplink scheduling	SU-PF	SU-PF	
Uplink MIMO mode	SU-MIMO with rank 2 adaptation	SU-MIMO with rank 2 adaptation for 2Tx with the best panel	
UE precoder scheme	Codebook based	Codebook based	
Uplink power control	$\alpha = 0.6, P_0 = -60$ dBm	$\alpha = 0.6, P_0 = -60$ dBm	
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	
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
	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
	SRS	2 symbols per 5 slots,	2 symbols per 5 slots,
	PTRS	N/A	N/A

ANNEX C

Link-level simulation parameters

The following document lists the simulation parameters introduced in the physical layer of 5G New Radio Rel-15 for link-level simulations. The obtained results were employed as an input to the system-level simulations presented in the Evaluation Report from the 5G Infrastructure Association

on the IMT-2020 proposal. The parameters apply to both Physical Downlink Shared Channel (PDSCH) and Physical Uplink Shared Channel (PUSCH).

TABLE 138

Link-level simulation parameters for PDSCH and PUSCH.

Parameter	Value
Number of subframes simulated	5000
Channel	AWGN
Bandwidth	10 MHz
Effective bandwidth	93.75%
Numerology	0
Carrier spacing	15 kHz
Cyclic prefix	Normal
DMRS symbols per slot	2
DMRS configuration type	1
Number of layers	1
Number of TX/RX antennas	1
Channel estimation method	Ideal
Modulation demapper	Maximum Likelihood (ML)
Minimum Block Error Rate	$\text{BLER} \leq 10^{-3}$ (0.1%)
Stop criterion per CNR	500 erroneous subframes

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