ETSI TR 137 911 V19.0.0 (2025-10)

TECHNICAL REPORT

LTE;
5G;
Study on self-evaluation towards the IMT-2020 submission of the 3GPP Satellite Radio Interface Technology
(3GPP TR 37.911 version 19.0.0 Release 19)

Reference
RTR/TSGR-0037911vj00

Keywords
5G,LTE

ETSI

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Contents

Foreword

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should indicates a recommendation to do something

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can indicates that something is possible

cannot indicates that something is impossible

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will indicates that something is certain or expected to happen as a result of action taken by an agency the behaviour of which is outside the scope of the present document

will not indicates that something is certain or expected not to happen as a result of action taken by an agency the behaviour of which is outside the scope of the present document

might indicates a likelihood that something will happen as a result of action taken by some agency the behaviour of which is outside the scope of the present document

might not indicates a likelihood that something will not happen as a result of action taken by some agency the behaviour of which is outside the scope of the present document

In addition:

is (or any other verb in the indicative mood) indicates a statement of fact

is not (or any other negative verb in the indicative mood) indicates a statement of fact

The constructions "is" and "is not" do not indicate requirements.

Introduction

This report presents the self-evaluation results of by 3GPP 5G (developed by 3GPP as 5G NTN, Release 17 and beyond) developed satellite technology.

From evaluation perspective, the technologies are evaluated against the technical performance requirements as defined in Report ITU-R M.2514[2] for eMBB-s, mMTC-s and HRC-S use cases, as well as spectrum requirements and service aspects requirements, using the evaluation criteria as defined in the report. Detailed self-evaluation results are provided through Section 4 to 7.

The conclusion is given in Section 8.

1 Scope

The present document reports on the self-evaluation results for meeting the requirements defined by ITU in Report ITU-R M.2514 [2].

2 References

The following documents contain provisions which, through reference in this text, constitute provisions of the present document.

- References are either specific (identified by date of publication, edition number, version number, etc.) or non-specific.
- For a specific reference, subsequent revisions do not apply.
- For a non-specific reference, the latest version applies. In the case of a reference to a 3GPP document (including a GSM document), a non-specific reference implicitly refers to the latest version of that document *in the same Release as the present document*.

[1] 3GPP TR 21.905: "Vocabulary for 3GPP Specifications".

[2] Report ITU-R M.2514: "Vision, requirements and evaluation guidelines for satellite radio interface(s) of IMT-2020".

[3] 3GPP TS 38.211: "NR; Physical channels and modulation".

[4] 3GPP TS 38.133: "NR; Requirements for support of radio resource management".

[5] 3GPP TS 38.101-5: "NR; User Equipment (UE) radio transmission and reception; Part 5: Satellite access Radio Frequency (RF) and performance requirements".

[6] 3GPP TS 38.108: "NR; Satellite Access Node radio transmission and reception".

[7] 3GPP TS 38.213: "NR; Physical layer procedures for control".

[8] 3GPP TS 38.214: "NR; Physical layer procedures for data".

[9] Report ITU-R M.2412: " Guidelines for evaluation of radio interface technologies for IMT-2020".

[10] 3GPP TS 36.102: "Evolved Universal Terrestrial Radio Access (E-UTRA); User Equipment (UE) radio transmission and reception for satellite access".

[11] 3GPP TS 36.108: "Evolved Universal Terrestrial Radio Access (E-UTRA); Satellite Access Node radio transmission and reception".

3 Definitions of terms, symbols and abbreviations

3.1 Terms

For the purposes of the present document, the terms given in TR 21.905 [1] and the following apply. A term defined in the present document takes precedence over the definition of the same term, if any, in TR 21.905 [1].

3.2 Symbols

For the purposes of the present document, the following symbols apply:

f Scaling factor can at least take the values 1 and 0.75.
$N_{PRB}^{BW,\mu}$ Maximum RB allocation in bandwidth BW with numerology μ; see clause 4.1

OH	Overhead calculated as the average ratio of the number of REs not used for data transmissions
P_{SSB}	SSB set periodicity; see clause 4.8.2
P_{SIB1}	SIB1 periodicity; see clause 4.8.2
Q_m	Maximum modulation order
R_{max}	Maximum code rate
R_p	Peak data rate
SE_p	Peak spectral efficiency
$Sleep\_ratio_{Slot\_based}$	Sleep ratio per slot basis; see clause 4.8.2
$Sleep\_ratio_{Symbol\_based}$	Sleep ratio per symbol basis; see clause 5.8.1
T_s^{μ}	OFDM symbol duration in a subframe for numerology; see clause 4.1
μ	Numerology (as defined in TS 38.211 [3])
v_{Layers}	Maximum number of layers
W_a	Assigned bandwidth

3.3 Abbreviations

For the purposes of the present document, the abbreviations given in TR 21.905 [1] and the following apply. An abbreviation defined in the present document takes precedence over the definition of the same abbreviation, if any, in TR 21.905 [1].

DL	Downlink
DRX	Discontinuous Reception
eMBB-s	Enhanced Mobile Broadband - satellite
FDD	Frequency division duplexing
FR1	Frequency range 1
FRF	Frequency Reuse Factor
HRC-s	High Reliability Communications - satellite
IoT NTN	Satellite components of NB-IoT and LTE -MTC
LTE-MTC	Long Term Evolution – Machine Type Communication
mMTC-s	Massive machine type communications – satellite
NB-IoT	Narrowband Internet of Things
NR NTN	Satellite component of NR
NTN	Non-terrestrial networks
OFDM	Orthogonal Frequency Division Multiplexing
PBCH	Physical Broadcast CHannel
PDCCH	Physical Downlink Control CHannel
PDSCH	Physical Downlink Shared CHannel
PRACH	Physical Random Access CHannel
PUCCH	Physical Uplink Control CHannel
PUSCH	Physical Uplink Shared CHannel
QoS	Quality of Service
RB	Resource block
RIT	Radio Interface Technology
RRM	Radio Resource Management
SCS	SubCarrier Spacing
SIB1	System Information Block Type 1
SINR	Signal to Interference and Noise Ratio
SRIT	Set of Radio Interface Technologies
SS	Synchronization Signal
SSB	SS/PBCH Block
TRxP	Transmission Reception Point
UL	Uplink

4 Self-evaluation of eMBB-s technical performance

4.1 Peak spectral efficiency

As defined in R MReport ITU-R M.2514 [2], peak spectral efficiency is the maximum data rate under ideal conditions normalized by the assigned bandwidth (in bit/s/Hz), where the maximum data rate is the received data bits assignable to a single mobile station, when up to 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 and guard bands).

When only one component carrier is in use, the generic formula for peak spectral efficiency is given by:

$$SE_p = \frac{v_{Layers} \cdot Q_m \cdot f \cdot R_{max} \frac{N_{PRB}^{BW,\mu} \cdot 12}{T_s^{\mu}} (1-OH)}{BW} \quad (4.1\text{-}1)$$

wherein

- R_{max} is the maximum code rate
- v_{Layers} is the maximum number of layers
- Q_m is the maximum modulation order
- f is the scaling factor can at least take the values 1 and 0.75
- μ is the numerology (as defined in TS 38.211 [3])
- T_s^{μ} is the average OFDM symbol duration in a subframe for numerology μ, i.e $T_s^{\mu} = \frac{10^{-3}}{14 \cdot 2^{\mu}}$. , assuming normal cyclic prefix
- $N_{PRB}^{BW,\mu}$ is the maximum RB allocation in bandwidth with numerology μ and BW is the UE supported maximum bandwidth in a given band.
- OH is the overhead calculated as the average ratio of the number of REs occupied by L1/L2 control, Synchronization Signal, PBCH, reference signals, etc. with respect to the total number of REs in the effective bandwidth time product as given by $(BW \cdot 14 \cdot T_s^{\mu})$.

The peak spectral efficiency of NR satellite access is evaluated based on an analytical method. Unlike a terrestrial system, where conditions close to ideal be achieved, for an NTN system the minimum orbit height will result in a signal-to-noise ratio where the theoretical maximum is not achievable. The evaluation assumptions for the ideal conditions can be found in Annex A.1.

The evaluation results for Peak spectral efficiency for DL and UL can be found in Table 4.1-1.

Table 4.1-1: NR satellite access peak spectral efficiency (bit/s/Hz)

Link	SCS [kHz]	BW [MHz/RB]	Peak spect. eff. (bits/s/Hz)	Req.
DL	15	30 / 160	3.71	3
UL	15	1.44 / 8	1.85	1.5

Based on the above analysis, NR satellite access fulfils peak spectral efficiency requirement for both DL and UL.

4.2 Peak data rate

Peak data rate for NR NTN is evaluated based on the evaluation results of NR satellite access peak spectral efficiency provided in Section 4.1.1. Using the analytical way as provided in Report ITU-R M.2514 [2] DL peak data rate is calculated as:

$$R_p = W_a \times SE_p \quad (4.2\text{-}1)$$

The evaluation results for Peak spectral efficiency for DL and UL can be found in Table 4.2-1.

Table 4.2-1: NR satellite access Peak data rate (Mbit/s)

Link	SCS [kHz]	BW [MHz/RB]	Peak data rate (Mbit/s)	Req.
DL	15	30 / 160	111	70
UL	15	1.44 / 8	2.67	2

Based on the above analysis, NR satellite access fulfils peak data rate requirements for both DL and UL.

4.3 5th percentile user spectral efficiency

As defined in Rep ITU-R M.2514 [2], 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.

As required by Report Rep ITU-R M.2514 [2], 5th percentile user spectral efficiency shall be assessed jointly with average spectral efficiency using the same simulation. Therefore, the evaluation results of the 5th percentile user spectral efficiency are provided together with average spectral efficiency in Section 4.4.

4.4 Average spectral efficiency

As defined in Report ITU-R M.2514 [2], average spectral efficiency is the aggregate throughput of all users (the number of correctly received bits, i.e. the number of bits contained in the SDUs delivered to Layer 3, over a certain period of time) divided by the channel bandwidth of a specific band divided by the number of TRxPs and is measured in bit/s/Hz/TRxP. A TRxP (transmission and reception point) refers to a beam generated by the satellite. The channel bandwidth for this purpose is defined as the effective bandwidth times the frequency reuse factor.

As required by Report ITU-R M.2514 [2], average spectral efficiency and 5th percentile user spectral efficiency are assessed jointly using the same simulation.

Average spectral efficiency and 5th percentile user spectral efficiency are evaluated for NR satellite access with satellite orbit at 600km with a ttransparent payload operating in S-Band. Both configurations with frequency reuse factor equals to 1 and frequency reuse factor equals to 3 are evaluated. Detailed evaluation assumptions and results can be found in Annex A.2.

The antenna configuration is indicated as (M, N, P, M_g,N_g; M_p, N_p), where M and N are the number of vertical, horizontal antenna elements within a panel, P is number of polarizations, M_g is the number of panels in a column, N_g is the number of panels in row; and M_p and N_p are the number of vertical, horizontal TXRUs within a panel and polarization.

The evaluation results of DL spectral efficiency for NR satellite access are provided in Table 4.4-1.

It is observed that NR satellite access can fulfil downlink spectral efficiency requirement.

Table 4.4-1*:* Evaluation results of DL spectral efficiency for NR satellite access

<table>
<tr><th>Scintillation loss</th><th>Number of UE antennas</th><th>Frequency reuse factor</th><th colspan="2">ITU Requirement</th><th>DL Spectral efficiency</th><th>Number of samples</th></tr>
<tr><td rowspan="8">2.2 dB</td><td rowspan="4">2</td><td rowspan="2">FRF = 1</td><td>Average [bit/s/Hz/TRxP]</td><td>0.500</td><td>0.572</td><td>9</td></tr>
<tr><td>5th percentile [bit/s/Hz]</td><td>0.030</td><td>0.031</td><td>9</td></tr>
<tr><td rowspan="2">FRF = 3</td><td>Average [bit/s/Hz/TRxP]</td><td>0.500</td><td>0.537</td><td>9</td></tr>
<tr><td>5th percentile [bit/s/Hz]</td><td>0.030</td><td>0.038</td><td>9</td></tr>
<tr><td rowspan="4">4</td><td rowspan="2">FRF = 1</td><td>Average [bit/s/Hz/TRxP]</td><td>0.500</td><td>0.746</td><td>2</td></tr>
<tr><td>5th percentile [bit/s/Hz]</td><td>0.030</td><td>0.036</td><td>2</td></tr>
<tr><td rowspan="2">FRF = 3</td><td>Average [bit/s/Hz/TRxP]</td><td>0.500</td><td>0.608</td><td>4</td></tr>
<tr><td>5th percentile [bit/s/Hz]</td><td>0.030</td><td>0.040</td><td>4</td></tr>
<tr><td rowspan="8">0 dB</td><td rowspan="4">2</td><td rowspan="2">FRF = 1</td><td>Average [bit/s/Hz/TRxP]</td><td>0.500</td><td>0.589</td><td>6</td></tr>
<tr><td>5th percentile [bit/s/Hz]</td><td>0.030</td><td>0.029</td><td>6</td></tr>
<tr><td rowspan="2">FRF = 3</td><td>Average [bit/s/Hz/TRxP]</td><td>0.500</td><td>0.562</td><td>6</td></tr>
<tr><td>5th percentile [bit/s/Hz]</td><td>0.030</td><td>0.038</td><td>6</td></tr>
<tr><td rowspan="4">4</td><td rowspan="2">FRF = 1</td><td>Average [bit/s/Hz/TRxP]</td><td>0.500</td><td>0.783</td><td>3</td></tr>
<tr><td>5th percentile [bit/s/Hz]</td><td>0.030</td><td>0.041</td><td>3</td></tr>
<tr><td rowspan="2">FRF = 3</td><td>Average [bit/s/Hz/TRxP]</td><td>0.500</td><td>0.659</td><td>3</td></tr>
<tr><td>5th percentile [bit/s/Hz]</td><td>0.030</td><td>0.047</td><td>3</td></tr>
</table>

The evaluation results of UL spectral efficiency for NR satellite access are provided in Table 4.4-2.

It is observed that NR satellite access can fulfil uplink spectral efficiency requirement.

Table 4.4-2: Evaluation results of UL spectral efficiency for NR satellite access

<table>
<tr><th>Scintillation loss</th><th>Number of UE antennas</th><th>Frequency reuse factor</th><th colspan="2">ITU Requirement</th><th>UL Spectral efficiency</th><th>Number of samples</th></tr>
<tr><td rowspan="4">2.2 dB</td><td rowspan="4">2</td><td rowspan="2">FRF = 1</td><td>Average [bit/s/Hz/TRxP]</td><td>0.100</td><td>0.145</td><td>9</td></tr>
<tr><td>5th percentile [bit/s/Hz]</td><td>0.003</td><td>0.006</td><td>9</td></tr>
<tr><td rowspan="2">FRF = 3</td><td>Average [bit/s/Hz/TRxP]</td><td>0.100</td><td>0.199</td><td>8</td></tr>
<tr><td>5th percentile [bit/s/Hz]</td><td>0.003</td><td>0.010</td><td>8</td></tr>
<tr><td rowspan="4">0 dB</td><td rowspan="4">2</td><td rowspan="2">FRF = 1</td><td>Average [bit/s/Hz/TRxP]</td><td>0.100</td><td>0.233</td><td>4</td></tr>
<tr><td>5th percentile [bit/s/Hz]</td><td>0.003</td><td>0.006</td><td>4</td></tr>
<tr><td rowspan="2">FRF = 3</td><td>Average [bit/s/Hz/TRxP]</td><td>0.100</td><td>0.230</td><td>5</td></tr>
<tr><td>5th percentile [bit/s/Hz]</td><td>0.003</td><td>0.009</td><td>5</td></tr>
</table>

4.5 User experienced data rate

As defined in Report ITU-R M.2514 [2], 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.

User experienced data rate for NR satellite access is evaluated under Rural – eMBB test environment. The user experienced data rate is derived from the 5th percentile user spectral efficiency through equation as defined in Report ITU-R M.2514 [2]. Detailed evaluation assumptions are based on spectral efficiency evaluation and can be found in Annex A.2.

The evaluation results of DL user experienced data rate for NR satellite access are provided in Table 4.5-1.

It is observed that NR satellite access can fulfil DL user experienced data rate requirement.

Table 4.5-1: Evaluation results of DL user experienced data rate for NR satellite access

Scintillation loss	Number of UE antennas	Frequency reuse factor	ITU Requirement (Mbit/s)	DL user experienced data rate (Mbit/s)	Number of samples
2.2 dB	2	FRF = 1	1	0.91	9
		FRF = 3	1	1.12	9
	4	FRF = 1	1	1.07	2
		FRF = 3	1	1.21	4
0 dB	2	FRF = 1	1	0.85	6
		FRF = 3	1	1.12	6
	4	FRF = 1	1	1.24	3
		FRF = 3	1	1.43	3

The evaluation results of UL user experienced data rate for NR satellite access are provided in Table 4.5-2.

It is observed that NR satellite access can fulfil UL user experienced data rate requirement.

Table 4.5-2: Evaluation results of UL user experienced data rate for NR satellite access

Scintillation loss	Number of UE antennas	Frequency reuse factor	ITU Requirement (Mbit/s)	UL user experienced data rate (Mbit/s)	Number of samples
2.2 dB	2	FRF = 1	0.1	0.15	9
		FRF = 3	0.1	0.28	8
0 dB	2	FRF = 1	0.1	0.13	4
		FRF = 3	0.1	0.26	5

4.6 Area traffic capacity

As defined in Report ITU-R M.2514 [2], area traffic capacity is the total traffic throughput served per geographic area (in Mbit/s/m^2). 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.

For NR satellite access, Area traffic capacity is evaluated under the Rural-eMBB-s test environment using analytical way based on the downlink average spectral efficiency as defined in in Report ITU-R M.2514 [2]. Detailed evaluation assumptions are based on spectral efficiency evaluation and can be found in Annex A.2.

The evaluation results of DL area traffic capacity NR satellite access a with 19 TRxP are provided in Table 4.6-1.

It is observed that NR satellite access can fulfil DL area traffic capacity requirement.

Table 4.6-1 Evaluation results of DL area traffic capacity for NR satellite access

Scintillation loss	Number of UE antennas	Frequency reuse factor	ITU Requirement (kbit/s/km2)	DL area traffic capacity (kbit/s/km2)	Number of samples
2.2 dB	2	FRF = 1	8	12.07	9
		FRF = 3	8	11.30	9
	4	FRF = 1	8	15.81	2
		FRF = 3	8	12.81	4
0 dB	2	FRF = 1	8	12.41	6
		FRF = 3	8	11.85	6
	4	FRF = 1	8	16.60	3
		FRF = 3	8	13.97	3

The evaluation results of UL area traffic capacity NR satellite access a with 19 TRxP are provided in Table 4.6-2.

It is observed that NR satellite access can fulfil UL area traffic capacity requirement.

Table 4.6-2 Evaluation results of UL area traffic capacity for NR satellite access

Scintillation loss	Number of UE antennas	Frequency reuse factor	ITU Requirement (kbit/s/km2)	UL area traffic capacity (kbit/s/km2)	Number of samples
2.2 dB	2	FRF = 1	1.5	3.06	9
		FRF = 3	1.5	4.19	8
0 dB	2	FRF = 1	1.5	4.87	4
		FRF = 3	1.5	4.84	5

4.7 Latency

4.7.1 General

As defined in Report ITU-R M.2514 [2], 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.

4.7.2 User plane latency

4.7.2.1 General

The evaluation of NR satellite access user plane latency is based on the procedure illustrated in Figure 4.7.2.1-1.

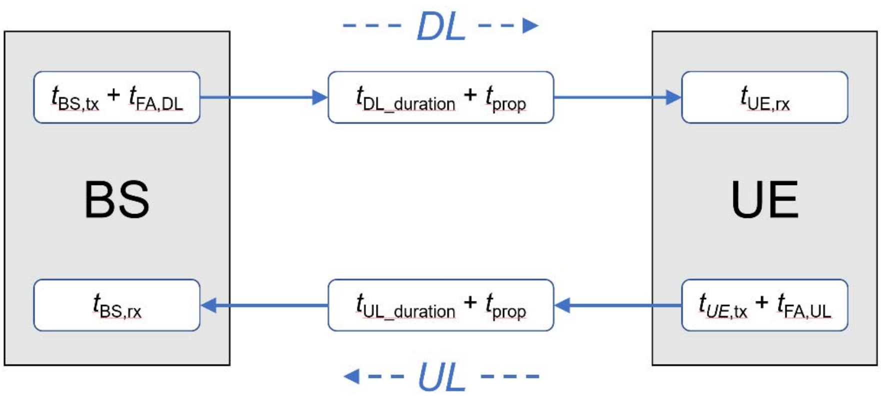

Figure 4.7.2.1-1 User plane procedure for evaluation

The detailed assumptions of each step are provided in Table 4.7.2.2-1 and Table 4.7.2.3-1 for downlink and uplink, respectively.

The additional assumptions to derive the evaluation results of of NR satellite access user plane latency are list as below.

- It is assumed that the packet arrives at any time of any OFDM symbol. In this case, the 0.5symbol 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 [8].
- It is assumed that PDCCH monitoring occasion occurs at every OFDM symbol in the evaluation.
- It is assumed that HARQ feedback is disabled, i.e., packet retransmissions are not considered.
- It is assumed an initial error probability of 0.
- It is assumed that satellite on-board delay can be considered negligible.

4.7.2.2 Downlink

The downlink procedure is abstracted in Table 4.7.2.2-1, where the assumptions of each step for evaluation are given.

Table 4.7.2.2-1: DL user plane procedure for of NR satellite access

ID	Component	Notations	Value
1	BS processing delay	$t_{BS,tx}$ The time interval between data arrival and packet generation.	$T_{proc,2}/2$, with $d_{2,1} = d_{2,2} = 0$. $T_{proc,2}$ is defined in Section 6.4 of TS 38.214 [8].
2	DL frame alignment (transmission alignment)	$t_{FA,DL}$ The time interval between packet generation and the next Tx opportunity.	T_{FA} Length of one slot, since T_{FA} is bounded by the slot duration.
3	TTI for DL data packet transmission	$t_{DL\_duration}$	Length of one slot (14 OFDM symbol length) or non-slot (4/7 OFDM symbol length), depending on slot or non-slot selected in evaluation.
4	One-way propagation time BS -> satellite -> UE	t_{prop}	RTD/2
5	UE processing delay	$t_{UE,rx}$ The time interval between PDSCH reception and decoding of the data.	$T_{proc,1}/2$, with $d_{1,1} = 0$. $T_{proc,1}$ is defined in Section 5.3 of TS 38.214 [8].
	Total one-way user plane latency for DL	$T_{DL} = (t_{BS,tx} + t_{FA,DL}) + (t_{DL\_duration} + t_{prop}) + t_{UE,rx}$	
Note: 1. The value is used for evaluation only; gNB processing delay may vary depending on implementation			

Based on the DL user plane procedure and assumptions given in Table 4.7.2.2-1, a variety of configurations and UE capabilities are evaluated for NR satellite access in Table 4.7.2.2-2.

Table 4.7.2.2-2: DL user plane latency for NR satellite access (ms)

DL user plane latency		UE processing capability 1		UE processing capability 2	
		SCS		SCS	
		15 kHz	30 kHz	15 kHz	30 kHz
Resource mapping Type A	M = 4 (4OS non-slot)	6.21	5.21	5.67	4.90
	M = 7 (7OS non-slot)	6.43	5.32	5.89	5.01
	M = 14 (14OS slot)	6.93	5.57	6.39	5.26
Resource mapping Type B	M = 2 (2OS non-slot)	5.78	5.00	5.25	4.69
	M = 4 (4OS non-slot)	5.71	4.96	5.18	4.65
	M = 7 (7OS non-slot)	5.93	5.07	5.39	4.76

It is observed that NR fulfils DL user plane latency requirement in a wide range of configurations.

In addition, it is indicated that NR satellite access has designed user plane downlink timers to support larger latencies, e.g., up to 650 ms, for the operation in other relevant satellite orbits (e.g., GSO).

4.7.2.3 Uplink

The uplink procedure using a grant free transmission is abstracted in Table 4.7.2.3-1, where the assumptions of each step for evaluation are given.

Table 4.7.2.3-1: UL user plane procedure for NR satellite access

ID	Component	Notations	Value
1.1	UE processing delay	$t_{UE,tx}$ The time interval between data arrival and packet generation.	$T_{proc,2}/2$, with $d_{2,1} = d_{2,2} = 0$. $T_{proc,2}$ is defined in Section 6.4 of TS 38.214 [8].
1.2	UL frame alignment (transmission alignment)	$t_{FA,UL}$ The time interval between packet generation and the next Tx opportunity.	T_{FA} Length of one slot, since T_{FA} is bounded by the slot duration.
1.3	TTI for UL data packet transmission	$t_{UL\_duration}$	Length of one slot (14 OFDM symbol length) or non-slot (4/7 OFDM symbol length), depending on slot or non-slot selected in evaluation.
1.4	One-way propagation time UE -> satellite -> BS	t_{prop}	RTD/2
1.5	BS processing delay	$t_{BS,rx}$ The time interval between PUSCH reception and decoding of the data.	$T_{proc,1}/2$, with $d_{1,1} = 0$. $T_{proc,1}$ is defined in Section 5.3 of TS 38.214 [8].
	Total UP latency for UL	$T_{UL} = (t_{UE,tx} + t_{FA,UL}) + (t_{UL\_duration} + t_{prop}) + t_{BS,rx}$	
Note: 1. The value is used for evaluation only; gNB processing delay may vary depending on implementation.			

Based on the UL user plane procedure and assumptions given in Table 4.7.2.3-1, a variety of configurations and UE capabilities are evaluated for NR satellite access in Table 4.7.2.3-2.

Table 4.7.2.3-2: UL user plane latency for NR satellite access with grant free transmission (ms)

UL user plane latency		UE processing capability 1		UE processing capability 2	
		SCS		SCS	
		15 kHz	30 kHz	15 kHz	30 kHz
Resource mapping Type A	M = 4 (4OS non-slot)	6.21	5.21	5.67	4.90
	M = 7 (7OS non-slot)	6.43	5.32	5.89	5.01
	M = 14 (14OS slot)	6.93	5.57	6.39	5.26
Resource mapping Type B	M = 2 (2OS non-slot)	5.78	5.00	5.25	4.69
	M = 4 (4OS non-slot)	5.71	4.96	5.18	4.65
	M = 7 (7OS non-slot)	5.93	5.07	5.39	4.76
	M = 14 (14OS slot)	6.93	5.57	6.39	5.26

It is observed that NR satellite access fulfils UL user plane latency requirement in a wide range of configurations.

In addition, it is indicated that NR satellite access has designed user plane uplink timers to support larger latencies, e.g., up to 650 ms, for the operation in other relevant satellite orbits (e.g., GSO).

4.7.3 Control plane latency

As defined in Report ITU-R M.2514 [2], 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).

For NR satellite access, control plane latency is evaluated from RRC_INACTIVE state to RRC_CONNECTED state. Figure 4.7.3-1 provides an example control plane flow for NR satellite access.

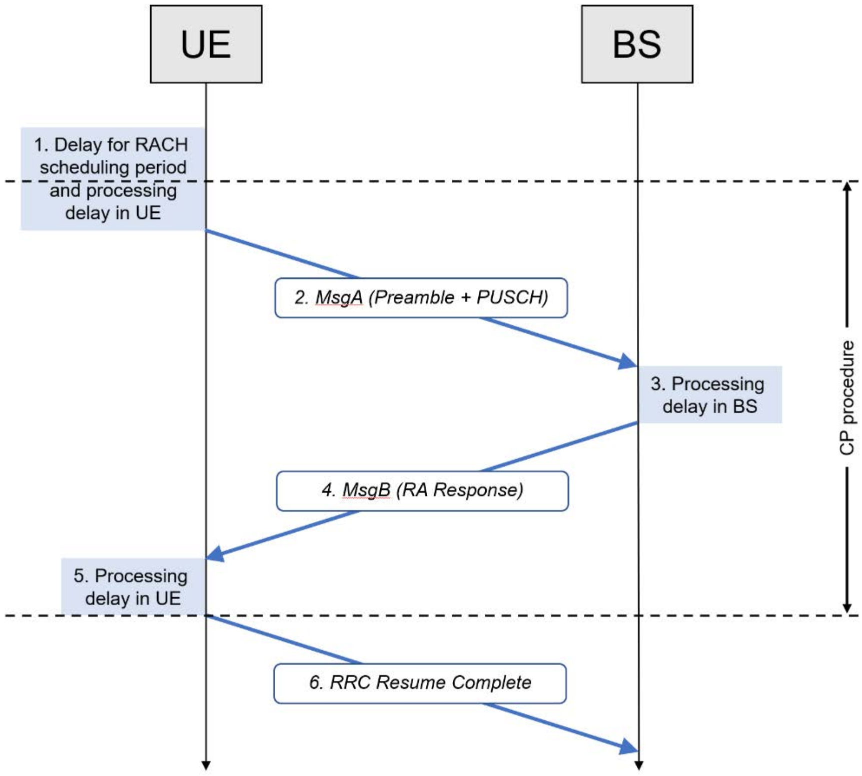

Figure 4.7.3-1: C-plane procedure (example for NR satellite access)

The detailed assumption of each step as shown in Figure 4.7.3-1 is provided in Table 4.7.3-1. 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 6 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.

NOTE: The delay values shown below do not include the waiting time for DL/UL subframe. It is only gNB or UE processing delay. The waiting time will be calculated, and it depends on the detailed DL/UL configuration.

Table 4.7.3-1: Assumption of C-plane procedure for NR satellite access

Step	Description	CP latency for UL data transfer
1.1	Delay due to RACH scheduling period (1TTI)	0
1.2	UE Processing Delay (L1 encoding of RRC Resume Request) for MsgA	$T_{proc,2}/2$ (assuming $d_2 = d_{2,1} = d_{2,2} = 0$)
2.1.1	Transmission of RACH preamble	Length of the preamble according to the PRACH format as specified in TS 38.211 [3]
2.1.2	Transmission interval	Length of the interval between PRACH and PUSCH transmissions as specified in TS 38.213 [7]
2.1.3	Transmission of PUSCH payload (RRCResumeRequest)	Ts (the length of 1 slot / non-slot)
2.2	Propagation delay UE -> BS	RTD/2
3	MsgA detection and processing delay in gNB (preamble, L2 and RRC)	3 ms
4.1	Transmission of MsgB (RA response)	Ts (the length of 1 slot / non-slot)
4.2	Propagation delay BS -> UE	RTD/2
5	Processing delay in UE of RRC Resume including RA response	7 ms
6	Transmission of RRC Resume Complete and data	0
NOTE 1: For step 1.1, 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. NOTE 2: For step 3, 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 3. Such delays may exist depending on deployment but are not within the scope of this evaluation. NOTE 3: For step 5 for UL data transfer, the processing delay in the UE (L2 and RRC) is considered, i.e., from reception of RRC Connection Resume including the RA response 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, 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. NOTE 4: For step 6, 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.		

In addition, the following assumptions apply to the evaluation:

- The transmission duration of Step 2 and 4 cannot be crossing the boundary of a slot;
- The CP procedure can start from the OFDM symbols within the slot that PRACH preamble can be transmitted (assuming that the slot is UL slot; otherwise, it will wait for the available UL slot).
- It is assumed that satellite on-board delay can be considered negligible.

Based on the control plane procedure and assumptions given in Table 4.7.3-1, a variety of configurations and UE capabilities are evaluated for NR for UL data transfer in Tables 4.7.3-2, 4.7.3-3 and 4.7.3-4.

Table 4.7.3-2: Control plane latency for NR satellite access (ms), PRACH length = 2 OFDM symbols

Resource mapping type	Non-slot duration	UE capability 1		UE capability 2	
		15kHz SCS	30kHz SCS	15kHz SCS	30kHz SCS
Type A	*M* =4 (4OS non-slot)	21.1	19.6	20.9	19.5
	M =7 (7OS non-slot)	21.5	19.8	21.3	19.7
Type B	*M*=2 (2OS non-slot)	20.5	19.3	20.3	19.2
	M =4 (4OS non-slot)	20.6	19.3	20.4	19.2
	M =7 (7OS non-slot)	21.0	19.5	20.8	19.4

Table 4.7.3-3: Control plane latency for NR satellite access (ms), PRACH length = 6 OFDM symbols

Resource mapping type	Non-slot duration	UE capability 1		UE capability 2	
		15kHz SCS	30kHz SCS	15kHz SCS	30kHz SCS
Type A	*M* =4 (4OS non-slot)	21.4	19.7	21.2	19.6
	M =7 (7OS non-slot)	21.8	19.9	21.6	19.8
Type B	*M*=2 (2OS non-slot)	20.8	19.4	20.6	19.3
	M =4 (4OS non-slot)	20.9	19.5	20.7	19.3
	M =7 (7OS non-slot)	21.3	19.7	21.1	19.6

Table 4.7.3-4 Control plane latency for NR satellite access (ms), PRACH length = 1 ms

Resource mapping type	Non-slot duration	UE capability 1		UE capability 2	
		15kHz SCS	30kHz SCS	15kHz SCS	30kHz SCS
Type A	*M* =4 (4OS non-slot)	21.9	20.5	21.8	20.4
	M =7 (7OS non-slot)	22.4	20.7	22.2	20.6
	M = 14 (14OS slot)	23.4	21.2	23.2	21.1
Type B	*M*=2 (2OS non-slot)	21.4	20.2	21.2	20.1
	M =4 (4OS non-slot)	21.4	20.2	21.2	20.1
	M =7 (7OS non-slot)	21.9	20.5	21.7	20.3

It is observed that NR satellite access fulfils the control plane latency requirement of 40 ms in a wide range of configurations.

In addition, it is indicated that NR satellite access has extended the range of a series of control plane session management timers to support larger latencies, e.g., up to 1.15 s, for the operation in other relevant satellite orbits (e.g., GSO).

4.8 Energy efficiency

4.8.1 General

As defined in Report ITU-R M.2514 [2], 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.

The RIT/SRIT shall have the capability to support a high sleep ratio and long sleep duration.

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 signalling (for the network) or the cycle of discontinuous reception (for the device) when no user data transfer takes place. The sleep duration is the continuous period of time with no transmission (for network and device) and reception (for the device).

4.8.2 Network side

4.8.2.1 General

The sleep ratio and sleep duration for NR satellite access network under unloaded case are evaluated.

When no data transfer takes place, NR satellite access network will keep periodical transmission of SS/PBCH blocks and SIB1 (remaining minimum system information), as well as paging signal in order for UEs to detect and access the radio network. The following mechanisms for SS/PBCH block, SIB1 and paging are assumed for the evaluation.

For SS/PBCH block transmission, the following configurations are considered in evaluation in FR1.

- One SS/PBCH block occupies 4 OFDM symbols with 20 RBs in one slot.
- One or multiple SS/PBCH block(s) compose an "SS burst set" (SSB set).
    - Denote L as the number of SS/PBCH blocks in an SSB set, where L can be 1~ 64. For below 3 GHz, the maximum value of L is 4; for below 7.125 GHz, the maximum value of L is 8.
- One SSB set transmission is confined to a half radio frame (5 ms) window
- The SSB set periodicity (P_{SSB}) can be configured to be {5, 10, 20, 40, 80, 160} ms
- The following mapping is used in a half radio frame for 15 and 30 kHz SCS
    - 2 SS/PBCH blocks are transmitted in one slot. And the L SS/PBCH blocks in an SSB set is transmitted in successive slots from the first slot in one SSB set period.

For SIB1 transmission, the following configurations are considered in evaluation.

- One SIB1 transmission occupies 2 OFDM symbols in one slot.
- SIB1 is multiplexed with SS/PBCH block using the following ways:
    - SIB1 is time division multiplexed (TDMed) with SS/PBCH block.
    - SS/PBCH block and SIB1 could be transmitted in the same slot
- SIB1 periodicity (P_{SIB1}) is assumed as follows:
    - 20ms for SSB set periodicity less than or equal to 20ms;
    - Otherwise SIB1 periodicity equals to SSB set periodicity.
- The following mapping is used
    - One SIB1 transmission corresponds to one SS/PBCH block
        - If L SS/PBCH block is transmitted, then L SIB1 transmissions are required.

- One slot accommodates 2 SIB1 transmissions.
- The offset of SIB1 transmission can be set as {0, 2, 5, 7}ms with respect to every 20ms time point. In the evaluation, the offset value that allows the closest SIB1 transmission to SS/PBCH block transmission is selected.

For paging occasion,

- The periodicity of paging occasion is the same as that of SSB set, and it is FDMed with an SS block.

Figure 4.8.2.1-1 illustrates NR SS/PBCH block and SIB1 transmission which employs the above-mentioned mechanism.

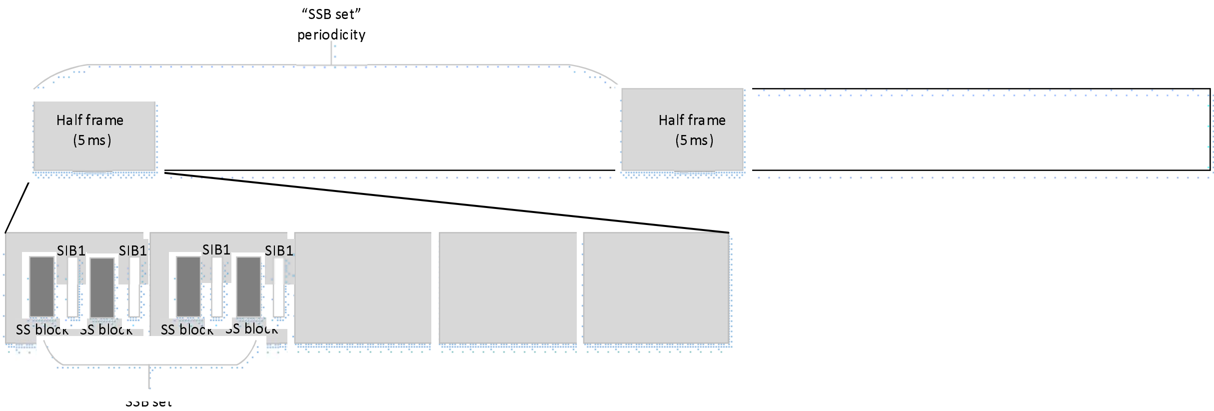

Figure 4.8.2.1-1 Illustration of NR SS/PBCH block and SIB1 transmission.

4.8.2.2 Evaluation of sleep ratio

Based on the above mechanisms, the sleep ratio per slot basis and per symbol basis are given as follows,

$$Sleep\_ratio_{Slot\_based} = 1 - \frac{\lceil L/2 \rceil}{2^{\mu} \times P_{SSB}} \qquad (4.8.2.2\text{-}1)$$

$$Sleep\_ratio_{Symbol\_based} = 1 - \frac{\frac{L \times 2}{7}}{2^{\mu} \times P_{SSB}} - \alpha \cdot \frac{\frac{L}{7}}{2^{\mu} \times P_{SIB1}} \qquad (4.8.2.2\text{-}2)$$

where $\lceil x \rceil$ indicates the ceiling of x, μ is the numerology (as defined in TS 38.211 [3], e.g., μ=0 for 15 kHz SCS and μ=1 for 30 kHz SCS), L is the number of SS/PBCH blocks in one SSB set, P_{SSB} is the SSB set periodicity, P_{SIB1} is the RSMI periodicity, and $\alpha = 1$.

Evaluation results are shown in Table 4.8.2.2-1 and Table 4.8.2.2-2, respectively, for slot level and symbol level sleep ratio. It is observed that with SSB set period of 5ms, more than 80% of sleep ratio can be obtained by NR satellite access network; with SSB set period of larger than 10ms, more than 90% of sleep ratio can be obtained by NR satellite access network. Higher sleep ratio is expected with finer sleep granularity, e.g., in symbol level. Note that a subset of configurations in terms of number of SSB per set is used to derive the results.

Therefore, NR network can achieve high sleep ratio in unloaded case.

Table 4.8.2.2-1 NR satellite access network sleep ratio in slot level

SSB configuration		**SSB set periodicity P_{SSB}**					
SCS [kHz]	**Number of SS/PBCH block per SSB set, *L***	5ms	10ms	20ms	40ms	80ms	160ms
15kHz	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%
30kHz	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%

Table 4.8.2.2-2 NR satellite access network sleep ratio in symbol level

SSB configuration		SSB set periodicity P_{SSB}					
SCS [kHz]	Number of SS/PBCH block per SSB set, *L*	5ms	10ms	20ms	40ms	80ms	160ms
15kHz	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%
30kHz	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%

4.8.2.3 Evaluation of sleep duration

Based on the above mechanisms, evaluation results of sleep duration are provided in Table 4.8.2.2-1. It is observed that with SSB set period of 160 ms, more than 150ms sleep duration can be obtained by NR satellite access network. Therefore, NR network can achieve long sleep duration in unloaded case.

Therefore, NR meets network side energy efficiency requirement.

Table 4.8.2.3-1 NR satellite access network sleep duration (ms) in slot level

SSB configuration		SSB set periodicity P_{SSB}					
SCS [kHz]	Number of SS/PBCH block per SSB set, *L*	5ms	10ms	20ms	40ms	80ms	160ms
15kHz	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
30kHz	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

4.8.3 Device side

4.8.3.1 General

The sleep ratio and sleep duration for NR satellite access UEs under unloaded case are evaluated.

For NR, DRX is supported for UEs in idle, inactive and connected states.

4.8.3.2 Evaluation of sleep ratio

For idle state and inactive state, the UE should monitor one paging occasion per discontinuous reception (DRX) cycle (which equals to the paging cycle), and the UE can use DRX to reduce power consumption. Before paging receiving, the SSB monitoring is needed. Also, RRM measurement(s), including intra- and inter-cell shall be performed.

The DRX cycle for idle state / inactive state UE consists of an "On Duration" during which the UE should perform SSB monitoring, paging monitoring and RRM measurement, and an “Off Duration” during which the UE can skip reception of downlink channels to save energy. It is illustrated in Figure 4.8.3.2-1.

Therefore, the sleep ratio is determined by the length of "On Duration" and the length of one paging cycle.

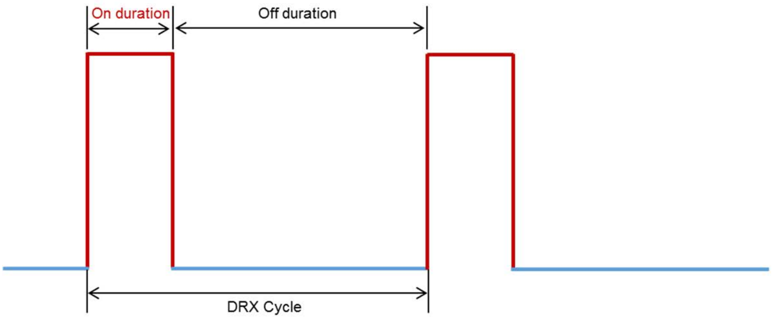

Figure 4.8.3.2-1 Illustration of DRX cycle in connected state

When DRX is used, the UE wakes up and receives SSB for synchronization, listens to PDCCH only on specific paging occasion defined in-terms of paging frame and subframe within period of N_{PC_RF} radio frames defined by the DRX cycle (paging cycle) of the cell and performs RRM measurement. The UE can remain in sleep mode for remaining duration within DRX cycle.

For synchronization, one SSB-burst set is assumed for short paging cycle (e.g., 320ms). Further, it is assumed that synchronization signal can be located in the same slot as paging-on slot and UE can finish network synchronization before paging monitoring. For longer paging cycle, one SSB-burst can still be assumed. In addition, to improve synchronization accuracy, the case of two SSB-burst sets is also evaluated. In this case, UE needs additional time up to one SSB cycle for SSB reception.

For paging monitoring, a paging occasion *can consist of multiple time slots (e.g. slot or OFDM symbol) where* paging DCI can be sent. In the evaluation, it is assumed that one paging occasion consists of one slot. On the other hand, one paging cycle consists of one or multiple Paging Frames. One Paging Frame may contain one or multiple paging occasion(s) or starting point of a PO. In the evaluation, it is assumed that one Paging Frame contains one paging occasion and time for paging monitoring is no longer than that of one SSB burst.

RRM measurement is based on SS/PBCH. In the evaluation, it is assumed that RRM measurement takes place in "On Duration" time, and the RRM measurement time is assumed to be 3ms for FR1 (see TS 38.133 [4]).

In addition to the above procedure, transition time is needed for UE to switch on / off its components. 10ms transition time is assumed for evaluation; but further reduced value is possible.

Based on the above analysis, the idle mode sleep ratio is evaluated with the configurations shown in Table 4.8.3.2-1. It is observed that more than 90% sleep ratio is achieved in idle mode by NR device.

Table 4.8.3.2-1 NR satellite access device sleep ratio in slot level (for idle / inactive mode)

Protocol state	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/ RRC_Inactive	2560	15	2	1	--	1	3	10	99.5%
	2560	15	2	1	160	2	3	10	93.2%

NOTE: For SSB period, "--" is assumed that SSB reception is during DRX-On time.

For connected state, if there is no data transmission in either downlink or uplink direction, the DRX mode is switched on.

The DRX cycle for connected state UE consists of an "On Duration" during which the UE should perform SSB monitoring, PDCCH monitoring (reflected as *DRX-onDurationTimer*), and RRM measurement, and an "Off Duration" during which the UE can skip reception of downlink channels to save energy. Also, transition time is assumed in "On Duration". The connected mode sleep ratio for different DRX cycles is shown in Table 4.8.3.2-2. Therefore, NR device can achieve high sleep ratio for both idle/inactive state and connected state in unloaded case.

Table 4.8.3.2-2 NR satellite access device sleep ratio in slot level (for connected mode)

Protocol state	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%
	2560	1	100	3	10	95.6%
	10240	1	1600	3	10	84.2%

NOTE: For SSB period, "--" is assumed that SSB reception is during DRX-On time.

4.8.3.3 Evaluation of sleep duration

The sleep duration for NR satellite access UE in idle mode is 2546ms for paging cycle of 2560ms with the assumed parameters.

The sleep duration of NR satellite access UE in connected state is 8627ms for paging cycle of 10240ms with the assumed parameters.

Consequently NR satellite access device can achieve very long sleep duration in both idle mode and connected mode.

It is therefore concluded that NR satellite access meets device side energy efficiency requirement.

4.9 Mobility

As defined in in Report ITU-R M.2514 [2], mobility is the maximum device speed at which a defined QoS can be achieved (in km/h). The QoS is defined as normalized traffic channel link data rate.

Both configurations with frequency reuse factor equal to 1 (FRF1) and frequency reuse factor equal to 3 (FRF3) are considered for mobility evaluation of the Rural-eMBB-s test environment. Detailed evaluation assumptions and results can be found in Annex A.3.

The evaluation results of mobility for NR satellite access for both evaluation configuration with FRF1 and FRF3 are provided in Table 4.9-1.

It is observed that NR satellite access fulfils the mobility requirement under 250 km/h.

Table 4.9-1 Evaluation results of NR satellite access mobility under 250 km/h

Frequency reuse factor	ITU Requirement		Evaluation results	Number of samples
FRF1	Normalized traffic channel link data rate (bit/s/Hz)	0.005	0.07	4
	Residual decoded packet error ratio	1%	0.18%	4
FRF3	Normalized traffic channel link data rate (bit/s/Hz)	0.005	0.14	4
	Residual decoded packet error ratio	1%	0.33%	4

4.10 Mobility interruption time

As defined in Report ITU-R M.2514 [2], 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 mobility 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 user terminal and base station, as applicable to the candidate RIT/SRIT.

For NR satellite access, the mobility interruption time is evaluated without cell and satellite change for the beam mobility scenario.

When moving within the same cell, the transmitting/receiving beam pair of the UE may need to be changed.

For DL data transmission during UE mobility, gNB can configure different beams for this UE at different slots. It ensures appropriate transmit beam allocation to the UE for continuous DL transmission. Therefore, DL data packet transmission is kept during beam pair switching at different slots.

For UL data transmission, PUSCH is sent using the beam configured by SRI (SRS resource indicator) by gNB. Accordingly, an appropriate gNB-side beam is selected for UL data reception. gNB may select different beams at different slots depending on the UE mobility. Therefore, UL data packet transmission is kept during beam pair switching at different slots.

Based on the above analysis, the UE can keep exchanging user plane packets with gNB during the mobility transitions without cell and satellite change. Therefore, 0ms mobility interruption time is achieved by NR satellite access for this scenario.

5 Self-evaluation of mMTC-s technical performance

5.1 Connection density

5.1.1 General

As defined in Report ITU-R M.2514 [2], connection density is the system capacity metric defined as the total number of devices fulfilling a specific quality of service (QoS) per unit area (per km^2).

The evaluation methodology follows section 8.2 in Report ITU-R M.2514 [2], with assumptions, including system level configurations and traffic model. The QoS evaluated is that a 32-byte packet is successfully received.

The Full-buffer system-level simulation approach followed by link level simulation (referred to as “full buffer system level simulation” below) has been used for the evaluation, following the methodology and principles outlined in section 7.1.3 of Report ITU-R M.2412 [9], adapted accordingly for satellite deployment.

In a first step this evaluation method employs a full buffer system level simulation to derive the uplink SINR distribution. In a second step link level simulation are performed to determine the uplink spectral efficiency and data rate as functions of SINR. When combined these three functions supports the calculation of the expected long-term time-frequency resources required for each SINR to support the specified traffic model.

Connection density is in a final step conceptually derived by the system bandwidth, declared for the candidate technology, divided by the average required frequency resource. The requirement is fulfilled if the recorded connection density exceeds the 500 devices/km^2, while the time resource, i.e. the packet delay, at the 99th percentile per user is less than 10 seconds and the utilized total bandwidth does not exceed 30 MHz.

This evaluation method is targeted to evaluate the connection density in terms of the capability of uplink data transmission. The capacity calculation is based on an assumption of ideal resource allocation among the multiple packets and users (e.g., there is no collision on resource allocation). The packet delay calculation does not consider the delays introduced by the connection access procedure. It also does not model synchronization and system information acquisition, control channel and downlink data channel performance.

5.1.2 NR satellite access

The connection density of NR satellite access is evaluated using the method described in clause 5.1.1. The Rural mMTC-s test environment is used for evaluation, with detailed evaluation assumptions as defined in Annex A.4 Configurations with frequency reuse factor (FRF) equal to 1 and 3 have been evaluated.

The evaluation results of NR satellite access (applicable for FDD frequency bands defined in 3GPP TS 38.108/38.101-5) are shown in Table 5.1.2-1 expressed as the average performance presented by the contributing companies. The bandwidth evaluated to be required to fulfil the requirement is also provided, noting that the minimum bandwidth required is determined by the minimum defined system channel bandwidth: 5 MHz for NR satellite access. It is observed that NR satellite access fulfills connection density requirement under full buffer system level simulation followed by link level simulation. In all cases, the 99th percentile packet delay per user was observed to achieve the <10 seconds target by a large margin. It is also observed that, using this methodology, the connection density will scale linearly with the bandwidth allocated.

Table 5.1.2-1 Evaluation results of connection density for NR satellite access (Full buffer system level simulation followed by link level simulation)

Traffic model	Frequency reuse factor	ITU Requirement (/km2)	Connection density(/km2)	Bandwidth (kHz)	Number of samples
1 message/day/device	FRF1	500	7205	180	4
	FRF3	500	27357	540	4
1 message/2 hours/device	FRF1	500	600	180	4
	FRF3	500	2277	540	4

5.1.3 IoT NTN

The connection density of IoT NTN (NB-IoT satellite access and eMTC satellite access) is evaluated using the method described in clause 5.1.1. The Rural mMTC-s test environment is used for evaluation, with detailed evaluation assumptions as defined in Annex A.4. Deployments with frequency reuse factor (FRF) equal to 1 and 3 have been evaluated.

The evaluation results of NB-IoT satellite access and eMTC satellite access (applicable for FDD frequency bands defined in 3GPP TS 36.108/36.102) are shown respectively in Table 5.1.3-1 and Table 5.1.3-2 expressed as the average performance presented by the contributing companies. The bandwidth evaluated to be required to fulfil the requirement is also provided, noting that the minimum bandwidth required is determined by the defined system channel bandwidth: 200kHz for NB-IoT satellite access and 1.4MHz for eMTC satellite access. It is observed that NB-IoT satellite access and eMTC satellite access both fulfil connection density requirement under full buffer system level simulation followed by link level simulation. In all cases, the 99th percentile packet delay per user was observed to achieve the <10 seconds target by a large margin. It is also observed that, using this methodology, the connection density will scale linearly with the bandwidth allocated.

Table 5.1.3-1 Evaluation results of connection density for NB-IoT satellite access (Full buffer system level simulation followed by link level simulation)

Traffic model	Frequency reuse factor	ITU Requirement (/km2)	Connection density(/km2)	Bandwidth (kHz)	Number of samples
1 message/day/device	FRF1	500	7218	180	5
	FRF3	500	32744	540	5
1 message/2 hours/device	FRF1	500	601	180	5
	FRF3	500	2728	540	5

Table 5.1.3-2 Evaluation results of connection density for eMTC satellite access (Full buffer system level simulation followed by link level simulation)

Traffic model	Frequency reuse factor	ITU Requirement (/km2)	Connection density(/km2)	Bandwidth (kHz)	Number of samples
1 message/day/device	FRF1	500	4940	180	1
	FRF3	500	18612	540	1
1 message/2 hours/device	FRF1	500	411	180	1
	FRF1	500	2470	1080	1
	FRF3	500	1551	540	1
	FRF3	500	9306	3240	1

6 Self-evaluation of HTC-s technical performance

6.1 Reliability

6.1.1 General

As defined in Report ITU-R M.2514 [2], 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.

The evaluation is conducted in the Rural-HRC-s test environment, applicable to handheld devices. Both downlink and uplink are evaluated. Detailed assumptions and results are provided in Annex A.5.

6.1.2 DL reliability

For downlink reliability, both evaluation configuration with frequency reuse factor equal to 1 and evaluation configuration with frequency reuse factor equal to 3 are evaluated.

The evaluation results of NR FDD for downlink reliability are provided in Table 6.1.2-1.

It is observed that NR satellite access fulfils the reliability requirement for downlink.

Table 6.1.2-1 Evaluation results of DL reliability for NR satellite access

Frequency Reuse Factor	ITU Requirement	DL Reliability	Number of samples
FRF 1	99.9%	99.98%	4
FRF 3	99.9%	99.96%	5

6.1.3 UL reliability

For uplink reliability, both evaluation configuration with frequency reuse factor equal to 1 and evaluation configuration with frequency reuse factor equal to 3 are evaluated.

The evaluation results of NR FDD for uplink reliability are provided in Table 6.1.3-2.

It is observed that NR satellite access fulfils the reliability requirement for uplink.

Table 6.1.3-2 Evaluation results of UL reliability for NR satellite access

Frequency Reuse Factor	ITU Requirement	UL Reliability	Number of samples
FRF 1	99.9%	99.97%	4
FRF 3	99.9%	99.97%	5

7 Self-evaluation of generic requirements

7.1 Service aspects

According to Report ITU-R M.2514-0 [x5], the support for wide range of services should be inspected by the following question:

- Does the proposal support a range of services? (eMBB-s, HRC-s, and mMTC-s)?

The evaluation method is defined in Report ITU-R M.2412 [9], and 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.

Based on the self-evaluation results in Section 5 to 7, it is observed that:

- For the standalone RIT, NR satellite access RIT can meet the minimum technical performance requirements for the three test environments in eMBB-s, HRC-s and mMTC-s, Therefore, the standalone RIT can fulfil the service requirements.

- For the SRIT, NR satellite access component RIT can meet the minimum technical performance requirements for the three test environments in eMBB-s, HRC-s and mMTC-s, and IoT NTN RIT can at least meet the minimum technical performance requirements for the one of the test environments in mMTC-s. Therefore, the SRIT can fulfil the service requirements.

7.2 Bandwidth

7.2.1 NR satellite access

The *transmission bandwidth configuration* N_{RB} for each *SAN channel bandwidth* and subcarrier spacing is specified in Table 7.2.1-1 for FR1 as explained in TS 38.108[6] and TS 38.101-5[5].

Table 7.2.1-1: Transmission bandwidth configuration N_{RB} for FR1

SCS (kHz)	5 MHz	10 MHz	15 MHz	20 MHz	30 MHz
	N_{RB}	N_{RB}	N_{RB}	N_{RB}	N_{RB}
15	25	52	79	106	160
30	11	24	38	51	78
60	N/A	11	18	24	38

The minimum guard band for each *SAN channel bandwidth* and SCS is specified in Table 7.2.1-2 for FR1.

Table 7.2.1-2 Minimum guard band (kHz) (FR1)

SCS (kHz)	5 MHz	10 MHz	15 MHz	20 MHz	30 MHz
15	242.5	312.5	382.5	452.5	592.5
30	505	665	645	805	945
60	N/A	1010	990	1330	1290

The number of RBs configured in any *SAN channel bandwidth* shall ensure that the minimum guard band specified in this clause is met.

7.2.2 IoT NTN

For NB-IoT satellite access, the *transmission bandwidth configuration* N_{RB} for *SAN and UE channel bandwidth* and subcarrier spacing is specified in Table 7.2.2-1, as documented in TS 36.108 [11] and TS 36.102 [10], where 15kHz subcarrier spacing is specified for downlink and uplink operation, and 3.75kHz subcarrier spacing is specified only for uplink operation.

Table 7.2.2-1: Transmission bandwidth configuration N_{RB}, $N_{tone\ 15kHz}$ and $N_{tone\ 3.75kHz}$ in NB-IoT satellite access channel bandwidth

Channel bandwidth $BW_{Channel}$ [kHz]	200
Transmission bandwidth configuration N_{RB}	1
Transmission bandwidth configuration $N_{tone\ 15kHz}$	12
Transmission bandwidth configuration $N_{tone\ 3.75kHz}$	48

For eMTC satellite access, the *transmission bandwidth configuration* N_{RB} for *SAN and UE channel bandwidth* and subcarrier spacing is specified in Table 7.2.2-2, as documented in TS 38.108 [6] and TS 38.101-5 [5].

Table 7.2.2-2: Transmission bandwidth configuration N_{RB} in eMTC satellite access channel bandwidth

Channel bandwidth $BW_{Channel}$ [MHz]	1.4
Transmission bandwidth configuration N_{RB}	6

The up to 30MHz scalable channel bandwidth to support the peak rate requirement for the SRIT is fulfilled via NR satellite access. The channel bandwidth for IoT NTN is not scalable at the UE because it is tailored for mMTC-s, where supporting high peak user data rates are less important than maintaining low device complexity. There is no aggregation support by the UE of multiple RF carriers. However, the system capacity can be scaled up by network deployment of multiple NB-IoT satellite access RF carriers or eMTC satellite access carriers, which enables to also scale up the user connection density and capacity.

7.3 Spectrum

7.3.1 NR satellite access

Corresponding to the definition of frequency ranges from TS 38.108[6], FR1 frequency range is defined based on 410 MHz – 7125 MHz frequency interval as represented in Table 7.3.1-1.

Table 7.3.1-1: Definition of frequency ranges

Frequency range designation	Corresponding frequency range
FR1	410 MHz – 7125 MHz

The Satellite Access Node and related UEs are designed to operate in the *operating bands* defined in Table 7.3.1-2.

Table 7.3.1-2: Satellite *operating bands* in FR1

Satellite *operating band*	Uplink (UL) *operating band* SAN receive / UE transmit $F_{UL,low}$ – $F_{UL,high}$	Downlink (DL) *operating band* SAN transmit / UE receive $F_{DL,low}$ – $F_{DL,high}$	Duplex mode
n256	1980 MHz – 2010 MHz	2170 MHz – 2200 MHz	FDD
n255	1626.5 MHz – 1660.5 MHz	1525 MHz – 1559 MHz	FDD
n254	1610 MHz – 1626.5 MHz	2483.5 MHz – 2500 MHz	FDD
NOTE: Satellite bands are numbered in descending order from n256.			

7.3.2 IoT NTN

IoT NTN is currently specified for operation in the *operating bands* defined in Table 7.3.2-1.

Table 7.3.2-1: Satellite *operating bands* in IoT NTN

Satellite *operating band*	Uplink (UL) *operating band* SAN receive / UE transmit $F_{UL,low}$ – $F_{UL,high}$	Downlink (DL) *operating band* SAN transmit / UE receive $F_{DL,low}$ – $F_{DL,high}$	Duplex mode
256	1980 MHz – 2010 MHz	2170 MHz – 2200 MHz	FDD
255	1626.5 MHz – 1660.5 MHz	1525 MHz – 1559 MHz	FDD
254	1610 MHz – 1626.5 MHz	2483.5 MHz – 2500 MHz	FDD
NOTE: Satellite bands are numbered in descending order from 256.			

8 Conclusions

Based on the self-evaluation results presented through Section 4 to 7, NR satellite access RIT fulfils all technical performance requirements in the three test environments: Rural – eMBB-s, Rural – mMTC-s, and Rural – HRC-s. IoT NTN RIT fulfils the technical performance requirements in at least one test environment: Rural – mMTC.

Both NR satellite access RIT and IoT NTN RIT fulfil the spectrum requirement.

5G NTN NR RIT and 5G NTN SRIT both fulfil the scalable bandwidth requirement by virtue of the scalable channel bandwidth supported by NR satellite access RIT.

It is therefore concluded that:

- 3GPP's 5G NTN SRIT fulfils the requirements and criteria for the Satellite Component of IMT-2020.
- 3GPP's 5G NTN NR RIT fulfils the requirements and criteria for the Satellite Component of IMT-2020.

Annex A: Simulation models and assumptions

A.1 Evaluation assumption for peak spectral efficiency and peak data rate for NR satellite access

Evaluation parameters for NR satellite access peak spectral efficiency and peak data rate is shown in Table A.1-1. The notations can be found in equation (4.1.1) in Section 4.1.

Table A.1.1 NR Parameters for peak spectral efficiency and peak data rate evaluation

Parameters	DL	UL	Remarks
Max. coding rate R_{max}	[666/1024 - 822/1024]	[434/1024 - 553/1024]	
Max. number of layers v_{Layers}	1		
Highest modulation order Q_m	6	4	DL: 64QAM UL: 16QAM
Scaling factor of modulation f	1		
Numerology μ	0		SCS = 15 kHz
Maximum RB allocation $N_{PRB}^{BW,\mu}$	160	8	For UL, 8 PRBs out of the full bandwidth is assigned per UE
Overhead (OH)	0.14	0.08	See 38.306, clause 4.1.2
Elevation angle	90°		
Orbit height [km]	600		
Frequency [GHz]	2.00		
TX: EIRP [dBm]	78.77	23.00	
RX: G/T [dB/T]	-31.62	1.10	
Atmospheric loss [dB]	0		
Shadow fading margin [dB]	0		
Scintillation loss [dB]	0		
Polarization loss [dB]	0		
Additional losses [dB]	0		

A.2 Evaluation assumption for spectral efficiency for NR satellite access

The detailed assumptions and results for average, 5th percentile user spectral efficiency, user experienced data rate and area traffic capacity can be found in the attached document "**A.2_eMBB_SE_ UserExpDataRate_AreaTrafCap.zip**".

A.3 Evaluation assumption for mobility for NR satellite access

The detailed assumptions and results for mobility can be found in the attached document "**A.3_Mobility.zip**"

A.4 Evaluation assumptions and results for connection density

The detailed assumptions and results for connection density can be found in the attached document "**A.4_ConnectionDensity.zip**".

A.5 Evaluation assumptions and results for reliability for NR satellite access

The detailed assumptions and results for reliability can be found in the attached document "**A.5_Reliability.zip**".

Annex B:
Calibration for self-evaluation

To facilitate the self-evaluation towards IMT-2020 submission of the 3GPP Satellite Radio Interface Technology, the system level simulators have been calibrated to ensure the results from different 3GPP entities are comparable.

The following metrics are selected for calibration of self-evaluation:

- DL Geometry
- Coupling loss: Coupling loss is defined as the signal loss from the antenna port to the antenna port.

The calibration was conducted to the corresponding evaluation configurations of case 9 (FRF 1) and case 10 (FRF 3). Detailed calibration parameters and assumptions are found in Section 6 of 3GPP TR 38.821. It should be noted that these parameters are used for calibration purpose only. It worth also noting that two additional tiers of beams for FRF 1 and three additional tiers of beams for FRF 3 are simulated for intra-satellite interference modelling. However, only the statistics of the UEs connecting to the inner 19 beams were collected (see Fig. 6.1.1.1.1 [TR 38.821] for the beam layout based on FRF configurations). For the calibration purpose, the ionospheric scintillation loss shall be considered equal to zero (i.e., the Ues are located between 20 and 60 degrees of latitude). The atmospheric absorptions loss shall be considered.

Fourteen 3GPP entities provided the calibration results, including ZTE, Thales, DOCOMO, Huawei, vivo, Nokia, CCU, ITRI, Qualcomm, Ericsson, CATT, Panasonic, CEWiT, and OPPO. The detailed assumptions and results for the calibration simulations can be found in the attached document "**B_Calibration.zip**".

The calibration results for the Rural eMBB-s environment with FRF1 and FRF3 are shown through Figure B-1 to Figure B-4, respectively. The results are based on the average of the results from the contributing entities.

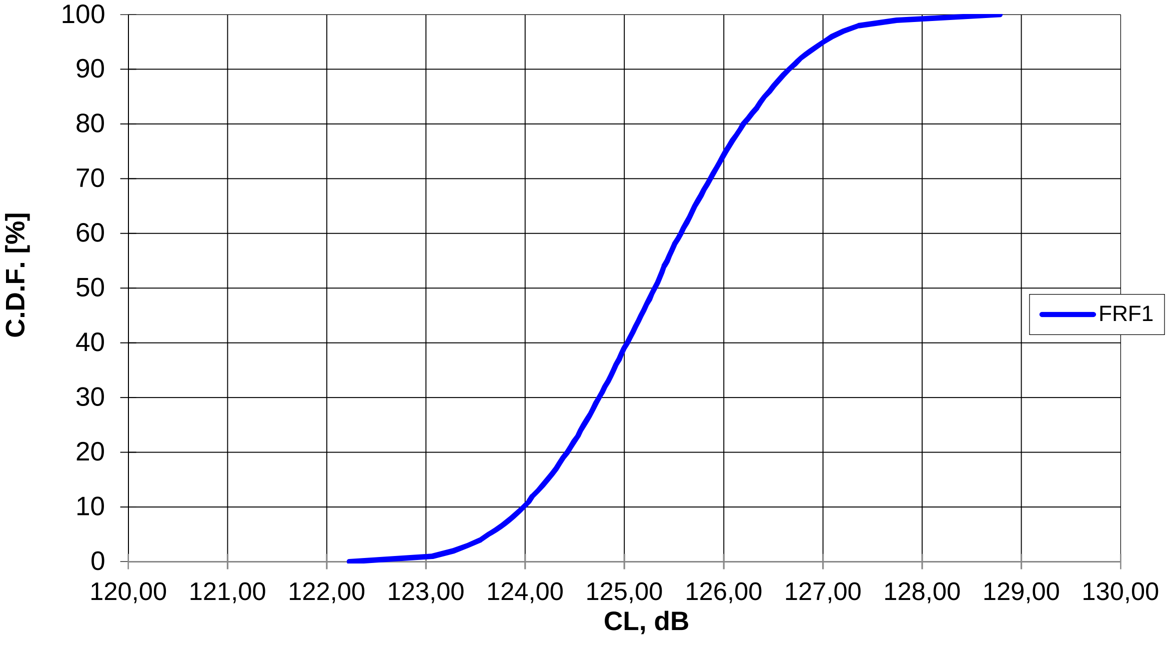

Figure B-1 Coupling loss of Rural eMBB-s with FRF1

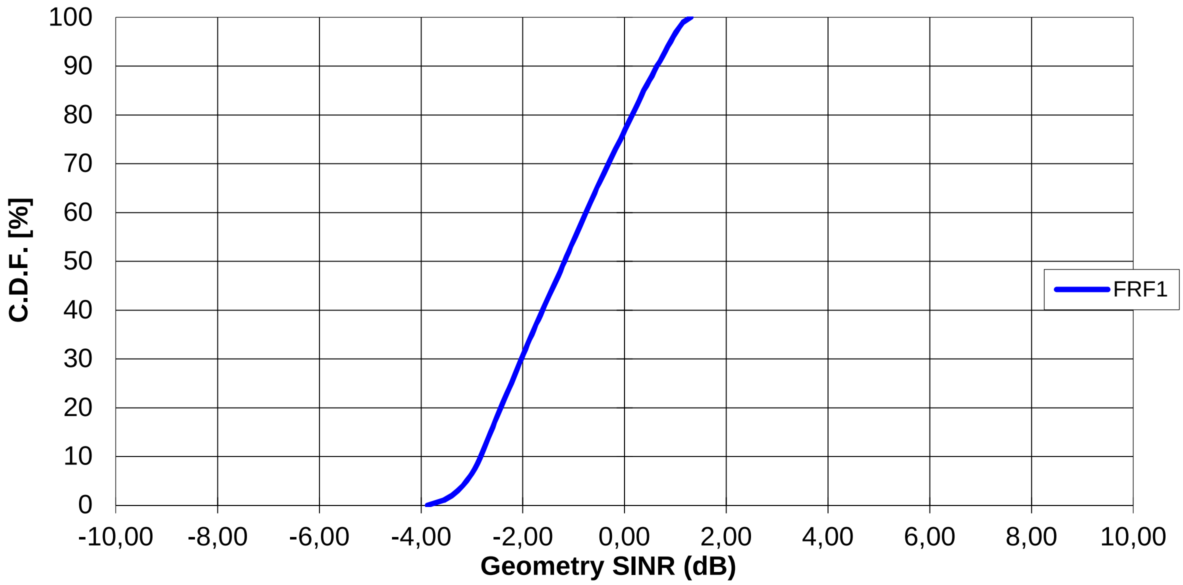

Figure B-2 Geometry SINR of Rural eMBB-s with FRF1

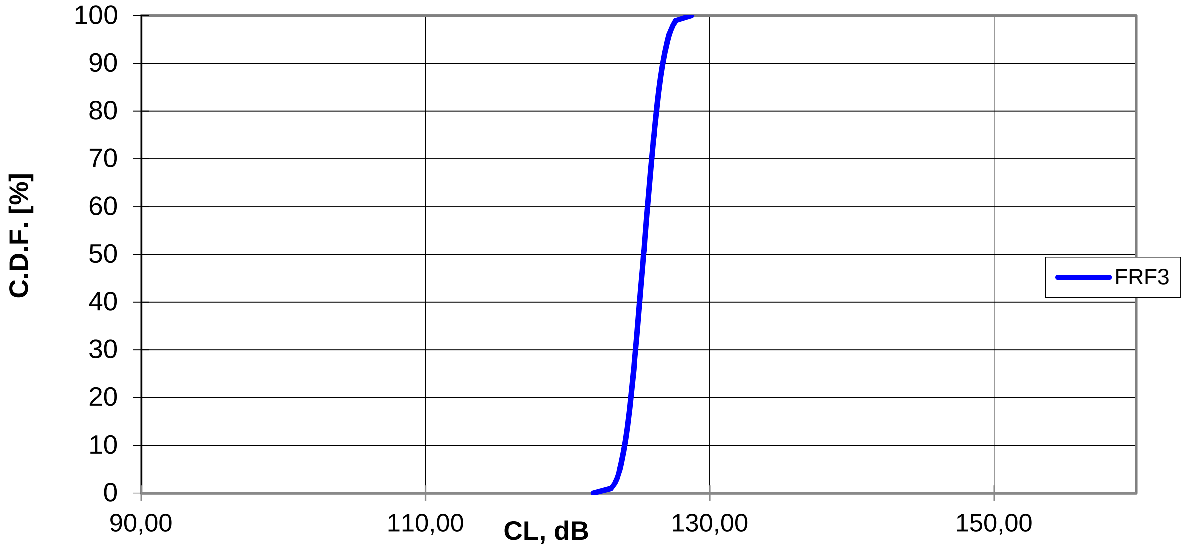

Figure B-3 Coupling loss of Rural eMBB-s with FRF3

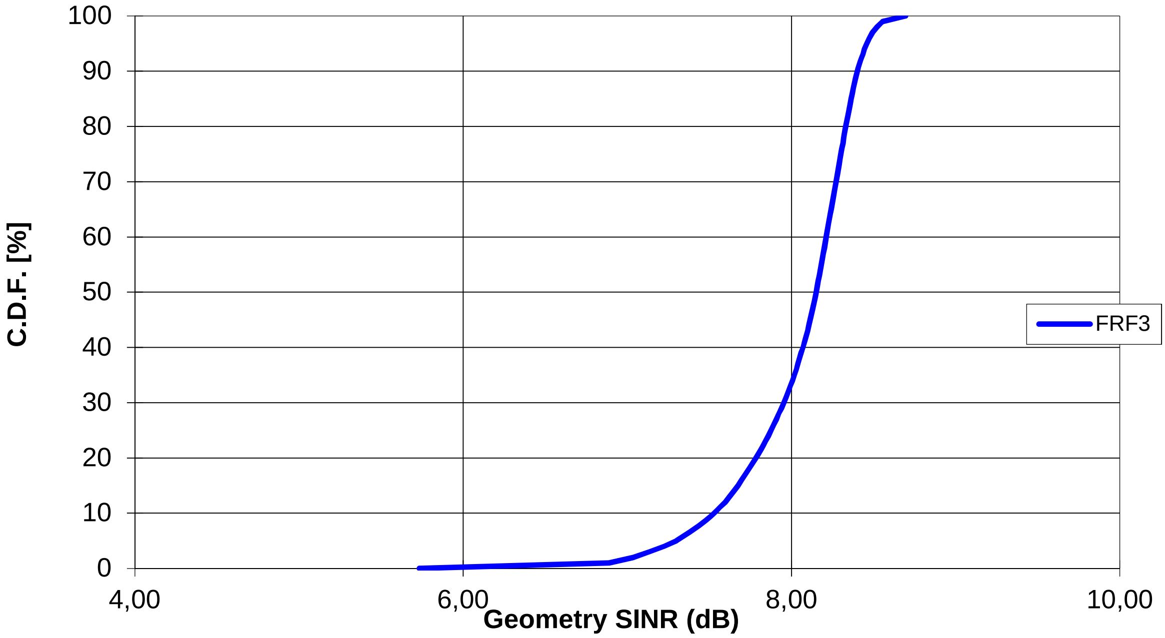

Figure B-4 Geometry SINR of Rural eMBB-s with FRF3

Annex C: ITU-R Submission Templates for IMT-2020 for Satellite Radio Interface Technology

C.1 Description template – characteristics

The characteristics template can be found in the attached document "**C.1_CharacteristicsTemplate.zip**".

C.2 Description template – link budget

The link budget template can be found in the attached document "**C.2_LinkBudgetTemplate.zip**".

C.3 Compliance templates for services, for spectrum, for technical performance

The compliance template can be found in the attached document "**C.3_ComplianceTemplate.zip**".

Annex D:
Change history

Change history							
Date	**Meeting**	**TDoc**	**CR**	**Rev**	**Cat**	**Subject/Comment**	**New version**
2023-06	RAN#100	RP-231403				TR skeleton for Study on self-evaluation towards the IMT-2020 submission of the 3GPP Satellite Radio Interface Technology	0.0.1
2023-09	RAN#101	RP-232645				Added text for agreements on peak spectral efficiency and peak data rate	0.1.0
2023-12	RAN#102	RP-23738				Withdrawn	0.1.1
2023-12	RAN#102	RP-233945				Updated with agreed pCRs	0.2.0
2023-12	RAN#102	RP-233980				For presentation to TSG RAN	1.0.0
2023-12	RAN #102	-				Approved v18.0.0	18.0.0
2024-03	RP-103	RP-240496	0001	-	D	Editorial corrections to TR 37.911	18.1.0
2025-09	RP-109	-	-	-	-	Upgrade to Rel-19 version without technical change	19.0.0

History

Document history		
V19.0.0	October 2025	Publication