|  |  |
| --- | --- |
| **Radiocommunication Study Groups** |  |
|  |  |
|  |  |
| Received: 11 September 2024  Source: Documents [IMT-2020-SAT/3](https://www.itu.int/md/R19-IMT.2020.SAT-C-0003/en), [IMT-2020-SAT/4](https://www.itu.int/md/R19-IMT.2020.SAT-C-0004/en)  Subject: Resolution [ITU-R 65](https://www.itu.int/pub/R-RES-R.65) | **Document 4B/57-E** |
| **12 September 2024** |
| **English only** |
| Alliance for Telecommunications Industry Solutions (ATIS) | |
| FINAL EVALUATION ANALYSIS FROM ATIS WTSC IMT-2020 INDEPENDENT EVALUATION GROUP ON THE 3GPP SUBMISSION(S) TOWARD IMT-2020 SATELLITE COMPONENT TECHNOLOGIES | |
|  | |

In accordance with the ITU-R Submission and Evaluation Process for IMT-2020 Satellite component (Doc. [IMT-2020-SAT/2](https://www.itu.int/md/R19-IMT.2020.SAT-C-0002/en)), the Alliance for Telecommunications Industry Solutions (ATIS) has established the ATIS WTSC IMT-2020 Independent Evaluation Group (IEG)[[1]](#footnote-1), with the aim of supporting the ITU-R WP 4B evaluation of IMT-2020 satellite component candidate technologies.

This document includes the evaluation analysis of the ATIS IEG related to the 3GPP RIT and SRIT submissions for IMT-2020 satellite component, as in the Attachment.

**Attachment**: 1

Attachment

Evaluation analysis from ATIS WTSC IMT-2020 SAT Independent Evaluation Group for the 3GPP Submissions of 5G NTN:   
SRIT ([Doc. IMT-2020-SAT/3](https://www.itu.int/md/R19-IMT.2020.SAT-C-0003/en)) and RIT ([Doc. IMT-2020-SAT/4](https://www.itu.int/md/R19-IMT.2020.SAT-C-0004/en))

TABLE OF CONTENTS

1 Scope 4

2 References 4

3 Abbreviations 4

4 Introduction 6

5 Evaluation of eMBB-s technical performance 7

5.1 Peak spectral efficiency 7

5.2 Peak Data Rate 7

5.3 5th percentile and Average spectral efficiency 8

5.4 User Experienced Data Rate 9

5.5 Area traffic capacity 10

5.6 Mobility 11

5.7 Latency 11

5.7.1 Control Plane Latency 12

5.7.2 User Plane Latency 12

5.8 Mobility Interruption time 12

5.9 Energy Efficiency 12

6 Evaluation of HRC-s technical performance 14

6.1 Reliability 14

7 Evaluation of mMTC-s technical performance 14

7.1 Connection density 14

8 Other requirements evaluation 15

8.1 Bandwidth 15

8.2 Other requirements 17

8.2.1 Support of wide range of services 17

8.2.2 Supported spectrum band(s)/ranges(s) 17

9 Summary and conclusions 18

Annex 1: Detailed eMBB-s Evaluation Results and Assumptions 20

Annex 2: Detailed HRC-s Evaluation Results and Assumptions 39

Annex 3: Detailed mMTC-s Evaluation Results and Assumptions 42

# Scope

This document provides the final evaluation analysis of ATIS WTSC IMT-2020 SAT Independent Evaluation Group (also referred to as ATIS IEG below) related to the technology submissions from 3GPP.

# 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

[1] Report [[ITU-R M.2514](https://www.itu.int/pub/R-REP-M.2514-2022)](https://www.itu.int/pub/R-REP-M/publications.aspx?lang=en&parent=R-REP-M.2410), Vision, requirements and evaluation guidelines for satellite radio interface(s) of IMT-2020.

[2] Report [ITU-R M.2412](https://www.itu.int/pub/R-REP-M.2412), Guidelines for evaluation of radio interface technologies for IMT-2020.

[3] 3GPP TR 37.911, Study on self-evaluation towards the IMT-2020 submission of the 3GPP Satellite Radio Interface Technology.

[4] 3GPP TS 36.102, Evolved Universal Terrestrial Radio Access (E-UTRA); User Equipment (UE) radio transmission and reception for satellite access.

[5] 3GPP TS 36.108, Evolved Universal Terrestrial Radio Access (E-UTRA); Satellite Access Node radio transmission and reception.

[6] 3GPP TS 38.101-5, NR; User Equipment (UE) radio transmission and reception; Part 5: Satellite access Radio Frequency (RF) and performance requirements.

[7] 3GPP TS 38.108, NR; Satellite Access Node radio transmission and reception.

[8] 3GPP TR 38.811, Study on New Radio (NR) to support non-terrestrial networks.

[9] 3GPP TR 38.821, Solutions for NR to support Non-Terrestrial Networks (NTN).

[10] 3GPP TR 38.211, NR; Physical channels and modulation.

[11] 3GPP TR 38.213, NR; Physical layer procedures for control.

[12] 3GPP TR 38.214, NR; Physical layer procedures for data.

[13] 3GPP TR 38.306, NR; User Equipment (UE) radio access capabilities.

[14] WRC-23 Final Acts, Footnote No. 5.388 and Resolution 212:  
<http://handle.itu.int/11.1002/pub/8225d4fb-en>

# Abbreviations

3GPP 3rd Generation Partnership Project

BLER Block error ratio

BS Base-station

BW Bandwidth

CCE Control channel element

CDF Cumulative distribution function

CSI Channel state information

CSI-RS Channel state information reference signal

DL Downlink

DMRS Demodulation reference signal

DRX Discontinuous Reception

eDRX Enhanced DRX

eMBB Enhanced mobile broadband

eMBB-s Enhanced mobile broadband satellite

eMTC Enhanced MTC

E-UTRA Evolved Universal Terrestrial Radio Access (LTE)

FDD Frequency division duplexing

FDM Frequency division multiplexing

FR Frequency Range

FRF Frequency Reuse Factor

gNB g-NodeB

HARQ Hybrid automatic repeat request

HRC Hyper Reliable Communication

HRC-s Hyper Reliable Communications satellite

IoT Internet of Things

ITU International Telecommunication Union

ITU-R ITU Radiocommunication Sector

LDPC Low-density parity code

LEO Low Earth Orbit

LoS Line-of-sight

MCS Modulation coding scheme

MIMO Multiple-Input Multiple-Output

mMTC massive Machine-Type Communications

mMTC-s massive Machine-Type Communications satellite

MTC Machine-Type Communications

NB-IoT Narrowband-Internet of Things

NLoS non-Line-of-sight

NR New Radio

NTN Non-Terrestrial Network

OFDM Orthogonal frequency division multiplexing

PBCH Primary broadcast channel

PDCCH Physical downlink control channel

PDSCH Physical downlink shared channel

PDU Protocol data unit

PRB Physical resource block

PUCCH Physical uplink control channel

PUSCH Physical uplink shared channel

QoS Quality-of-service

RAN Radio access network

RB Resource block

RIT Radio-interface technology

SAN Satellite Access Node

SCS Sub-carrier spacing

SDU Service data unit

SE Spectral efficiency

SIB System Information Block

SINR/SNR Signal-to-interference noise ratio/Signal-to-noise ratio

SRIT Set of RITs

SS Synchronisation signal

SSB Synchronisation signal block

TBS Transport block size

TDD Time division duplexing

TPR Technical Performance Requirement

TRxP Transmission and reception point

TTI Transmission time interval

UE User equipment

UL Uplink

# Introduction

This document describes the ATIS IEG evaluation results and analysis for the IMT-2020 satellite candidate technology submissions by 3GPP. The following were collectively evaluated:

* 3GPP PROPONENT SUBMISSION OF SRIT ([Doc. IMT-2020-SAT/3](https://www.itu.int/md/R19-IMT.2020.SAT-C-0003/en))
  + NR NTN RIT and IoT NTN RIT
* 3GPP PROPONENT SUBMISSION OF RIT ([Doc. IMT-2020-SAT/4](https://www.itu.int/md/R19-IMT.2020.SAT-C-0004/en))
  + NR NTN RIT (same as SRIT)

Sections 5, 6 and 7 of this report include evaluation of eMBB-s, HRC-s and mMTC-s technical performance requirements, based on detailed assumptions captured in Annexes 1-3. Section 8 includes other requirements (bandwidth, spectrum and services). Section 9 provides final summary and conclusions.

# 5 Evaluation of eMBB-s technical performance

## 5.1 Peak spectral efficiency

This section covers the evaluation of the following TPR (as defined in [1]).

***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).*

The evaluation is based on 3GPP 5G NR NTN, applicable to both the 3GPP RIT and SRIT submissions.

An overall summary of evaluation results is captured in the following table.

Table 5.1

Summary of evaluation results for Peak spectral efficiency (bit/s/Hz/TRxP)

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| Scenario /TE | DL/ UL | IMT-2020 Target | 3GPP  Results | ATIS IEG results | | |
| A | B | **Results  Range** |
| **eMBB-s** | DL | 3 | 3.71 | 3.2 | 3.66-4.00 | **3.2-4** |
| **eMBB-s** | UL | 1.5 | 1.85 | 1.6 | 1.54-1.82 | **1.54-1.82** |

Details of individual evaluation results and assumptions are captured in Annex 1.

Conclusions:

Based on the evaluation results above, it is observed that NR NTN can meet the IMT-2020 requirements.

## 5.2 Peak Data Rate

This section covers the evaluation of the following TPR (as defined in [1]).

***Peak data rate*** *is the maximum achievable data rate under ideal conditions, which 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, guard bands and guard times).*

As per ITU-R guidelines, such TPR is derived from the Peak spectral efficiency.

The evaluation is based on 3GPP 5G NR NTN, applicable to both the 3GPP RIT and SRIT submissions.

An overall summary of evaluation results is captured in the following table.

Table 5.2

Summary of evaluation results for Peak Data Rate ([unit])

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| Scenario /TE | DL/ UL | IMT-2020 Target | 3GPP  Results | ATIS IEG results | | |
| A | B | **Results  Range** |
| **eMBB-s** | DL | 70 | 111 | 97.4 | 109.82-119.99 | **97.4-119.99** |
| **eMBB-s** | UL | 2 | 2.67 | 2.4 | 2.22-2.62 | **2.22-2.62** |

Details of individual evaluation results and assumptions are captured in Annex 1.

Conclusions:

Based on the evaluation results above, it is observed that NR NTN can meet the IMT-2020 requirements.

## 5.3 5th percentile and Average spectral efficiency

This section covers the simulation-based evaluation of the following TPRs (as defined in [1]).

***‒ 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.*

***‒ 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.*

The evaluation is based on 3GPP 5G NR NTN, applicable to both the 3GPP RIT and SRIT submissions.

An overall summary of simulation results is captured in the following tables, for NR NTN.

Table 5.3.1

Summary of simulation results for User (5%-ile) spectral efficiency (bit/s/Hz)

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| Scenario /TE | DL/ UL | IMT-2020 Target | 3GPP  Results | ATIS IEG results (NR NTN) | | |
| A | B | **Results  Range** |
| **eMBB-s Rural** | DL | 0.03 | 0.029~0.047 | 0.030-0.033 | 0.033-0.054 | **0.030-0.054** |
| **eMBB-s Rural** | UL | 0.003 | 0.006~0.010 | 0.004 | 0.015-0.022 | **0.004-0.022** |

Table 5.3.2

Summary of simulation results for Average spectral efficiency (bit/s/Hz/TRxP)

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| Scenario /TE | DL/ UL | IMT-2020 Target | 3GPP  Results | ATIS IEG results (NR NTN) | | |
| A | B | **Results  Range** |
| **eMBB-s Rural** | DL | 0.5 | 0.562~0.783 | 0.491-0.505 | 0.527-0.569 | **0.491-0.569** |
| **eMBB-s Rural** | UL | 0.1 | 0.145~0.233 | 0.155 | 0.248-0.275 | **0.155-0.275** |

Details of individual simulation results and assumptions are captured in Annex 1.

Conclusions:

Based on the evaluation results above, it is observed that NR NTN can meet the IMT-2020 requirements.

## 5.4 User Experienced Data Rate

This section covers the evaluation of the following TPR (as defined in [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. Let W denote the channel bandwidth and SEuser denote the 5th percentile user spectral efficiency, then the user experienced data rate, Ruser is given by:*

An overall summary of evaluation results is captured in the following table, for NR NTN.

Table 5.4

Summary of evaluation results for User Experienced Data Rate ([Mbit/s])

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| Scenario /TE | DL/ UL | IMT-2020 Target | 3GPP  Results | ATIS IEG results (NR NTN) | | |
| A | B | **Results  Range** |
| **eMBB-s Rural** | DL | 1 | 0.85~1.43 | 0.92-1.01 | 0.99-1.62 | **0.92-1.62** |
| **eMBB-s Rural** | UL | 0.1 | 0.13~0.28 | 0.13 | 0.45-0.66 | **0.13-0.66** |

The evaluation is based on 3GPP 5G NR NTN, applicable to both the 3GPP RIT and SRIT submissions.

Details of individual evaluation results and assumptions are captured in Annex 1.

Conclusions:

Based on the evaluation results above, it is observed that NR NTN can meet the IMT-2020 requirements.

## 5.5 Area traffic capacity

This section covers the evaluation of the following TPR (as defined in [1]).

***Area traffic capacity*** *is the total traffic throughput served per geographic area (in Mbit/s/km2). 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. Let W denote the channel bandwidth and ρ the TRxP density (TRxP/m2). The area traffic capacity Carea is related to average spectral efficiency SEavg as follows:*

The evaluation is based on 3GPP 5G NR NTN, applicable to both the 3GPP RIT and SRIT submissions.

An overall summary of evaluation results is captured in the following table, for NR NTN.

Table 5.5

Summary of evaluation results for Area traffic capacity ([kbit/s/km2])

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| Scenario /TE | DL/ UL | IMT-2020 Target | 3GPP  Results | ATIS IEG results (NR NTN) | | |
| A | B | **Results  Range** |
| **eMBB-s Rural** | DL | 8 | 11.30~16.60 | 10.42-10.70 | 9.34-10.08 | **9.34-10.70** |
| **eMBB-s Rural** | UL | 1.5 | 3.06~4.87 | 3.28 | 4.39-4.87 | **3.28-4.87** |

Details of individual simulation results and assumptions are captured in Annex 1.

Conclusions:

Based on the evaluation results above, it is observed that NR NTN can meet the IMT-2020 requirements.

## 5.6 Mobility

This section covers the evaluation of the following TPR (as defined in [1]).

***Mobility*** *is the maximum device speed at which a defined QoS (Normalized traffic channel link data rate (bit/s/Hz)) can be achieved (in km/h).*

The evaluation is based on 3GPP 5G NR NTN, applicable to both the 3GPP RIT and SRIT submissions.

An overall summary of simulation results is captured in the following table, for NR NTN.

Table 5.6

Summary of evaluation results for Mobility ([bit/s/Hz, at 250 km/h])

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| **Scenario /TE** | **DL/ UL** | **IMT-2020 Target** | **3GPP  Results** | **ATIS IEG results (NR NTN)** | | |
| A | B | **Results  Range** |
| **eMBB-s Rural** | N.A | 0.005 | 0.07~0.14 | 0.203 | 0.07 (FRF1)  0.14 (FRF3) | **0.07-0.203** |

Details of individual simulation results and assumptions are captured in Annex 1.

Conclusions:

Based on the evaluation results above, it is observed that NR NTN can meet the IMT-2020 requirements.

## 5.7 Latency

This section covers the evaluation of the following TPRs (as defined [1]).

***‒ Control Plane latency****: 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). Control plane latency should be equal to or less than 40 ms]*

***‒ User Plane latency****: 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. User plane latency should be equal to or less than 10 ms, for both downlink and uplink, assuming unloaded conditions*

A summary of evaluation results is captured in the following sub-sections.

The evaluation is based on 3GPP 5G NR NTN, applicable to both the 3GPP RIT and SRIT submissions.

Details of individual evaluation results and assumptions are captured in Annex 1.

### 5.7.1 Control Plane Latency

Table 5.7.1

Control plane latency for NR satellite access for LEO satellite at 600 km altitude

|  |  |
| --- | --- |
| UE processing capability 1 | **22.36 ms** |
| UE processing capability 2 | **22.18 ms** |

Conclusions:

Based on the above evaluation results, it is observed that, with LEO satellite at 600 km altitude, NR NTN meets the minimum requirement for user plane latency.

### 5.7.2 User Plane Latency

Table 5.7.2

User plane latency for NR satellite access for LEO satellite at 600 km altitude

|  |  |  |
| --- | --- | --- |
| *User plane latency* | *UL* | *DL* |
| UE processing capability 1 | **6.72 ms** | **6.72 ms** |
| UE processing capability 2 | **6.36 ms** | **6.36 ms** |

## 5.8 Mobility Interruption time

This section covers the evaluation of the following TPR (as defined in [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 satellite and/or gateway node during transitions.*

The evaluation is based on 3GPP 5G NR NTN, applicable to both the 3GPP RIT and SRIT submissions.

For NR NTN, the best-case mobility interruption time can be achieved considering beam mobility scenarios, i.e. when the transmitting/receiving beam pair of the UE changes (assuming no cell and satellite change).

In such scenarios, for DL data transmission gNB can ensure appropriate transmit beam allocation to the UE for continuous DL transmission. Likewise, for UL data transmission an appropriate gNB-side beam can be selected for data reception, ensuring continuous UL data packet transmission during beam pair switching.

Conclusions:

Based on the above, mobility interruption time can be 0ms, fulfilling the IMT-2020 requirement (<50 ms).

## 5.9 Energy Efficiency

This section covers the evaluation of the following TPR (as defined in [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.*

*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 signalling (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 applies to the eMBB-s usage scenario and can be assessed qualitatively (no quantitative target). The RIT/SRIT shall have the capability to support a high sleep ratio and long sleep duration.*

The evaluation is based on 3GPP 5G NR NTN, applicable to both the 3GPP RIT and SRIT submissions.

Following TR 37.911 [3] assumptions and formulas, the following evaluation observations and results are achieved.

Network energy efficiency

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.

Results are shown below, using Number of SS/PBCH block per SSB set = 1, SSB set periodicity = 160 ms, SSB SCS = 15 kHz.

Table 5.9.1

NR NTN network sleep ratio and duration (slot level)

|  |  |
| --- | --- |
| Sleep Ratio | Sleep Duration (ms) |
| **99.4%** | **159** |

Device (UE) energy efficiency

For NR NTN, DRX is supported for UEs in idle, inactive and connected states. Evaluation results are summarized below.

Table 5.9.2

NR NTN UE sleep ratio (slot level) and duration for idle / inactive mode

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| DRX cycle (ms) | SCS (kHz) | SSB cycle (ms) | Sleep ratio | Sleep duration  (ms) |
| 2560 | 15 | 160 | **93.2%** | **~2 540** |

Table 5.9.3

NR NTN UE sleep ratio (slot level) and duration for connected mode

|  |  |  |  |
| --- | --- | --- | --- |
| DRX cycle (ms) | DRX-on Duration (ms) | Sleep ratio | Sleep duration  (ms) |
| 10240 | 1600 | **~90%** | **~8 600** |

Conclusions:

Based on the evaluation results above, it is observed that NR NTN can meet the energy efficiency requirements of high sleep ratio and long sleep duration

# 6 Evaluation of HRC-s technical performance

## 6.1 Reliability

This section covers the evaluation of the following TPR (as defined in [1]).

***‒ 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 based on 3GPP 5G NR NTN, applicable to both the 3GPP RIT and SRIT submissions.

An overall summary of simulation results is captured in the following table, for NR NTN.

Table 6.1

Summary of evaluation results for Reliability ([%])

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| **Scenario /TE** | **IMT-2020 Target** | **3GPP  Results** | **ATIS IEG results (NR NTN)** | | |
| A | B | **Results  Range** |
| **HRC-s Rural** | 99.9% (1-10−3) | UL: 99.97  DL: 99.96~99.98 | UL: 99.96  DL: 99.97~99.99 | UL: 99.99  DL: 99.99 | **UL: 99.96~99.99**  **DL: 99.97~99.99** |

Details of individual simulation results and assumptions are captured in Annex 2.

Conclusions:

Based on the evaluation results above, it is observed that NR NTN can meet the IMT-2020 requirements.

# 7 Evaluation of mMTC-s technical performance

## 7.1 Connection density

This section covers the evaluation of the following TPR (as defined in [1]).

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

The evaluation is based on 3GPP 5G NR NTN (applicable to both the 3GPP RIT and SRIT submissions), as well as 5G IoT NTN (part of the 3GPP SRIT submission).

An overall summary of simulation results is captured in the following tables, for NR NTN (Table 1) and IoT NTN (Table 2).

Table 7.1.1

Summary of evaluation results for Connection density ([devices/km2]), NR NTN

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| Scenario /TE | IMT-2020 Target | 3GPP  Results | ATIS IEG results | | |
| mMTC-s Rural | 500 | [180 kHz BW]  600 ~ 7205 | A | B | Results Range |
| [180 kHz BW]  2322 | [180 kHz BW]  5368 | [180 kHz BW]  **2322~5368** (Note 1) |
| Note 1: Results refer to FRF=3 and 1 message/2 hours/device assumptions. | | | | | |

Table 7.1.2

Summary of evaluation results for Connection density ([device/km2]), IoT NTN

|  |  |  |  |
| --- | --- | --- | --- |
| Scenario /TE | IMT-2020 Target | 3GPP  Results | ATIS IEG results |
| **mMTC-s Rural** | 500 | [180 kHz BW]   NB-IoT: 601 ~ 7218  eMTC: 411 ~ 4940 | [180 kHz BW]  NB-IoT: **1994**  eMTC: **1551**  (Note 1) |
| Note 1: Results refer to FRF=3 and 1 message/2 hours/device assumptions. | | | |

Details of individual simulation results and assumptions are captured in Annex 3.

Conclusions:

Based on the evaluation results above, it is observed that both NR NTN and IoT NTN can meet the IMT-2020 requirements.

# 8 Other requirements evaluation

This section evaluates remaining TPR and other requirements via inspection.

## 8.1 Bandwidth

Based on [1], the bandwidth is the maximum aggregated system bandwidth. Scalable bandwidth is the ability of the candidate RIT/SRIT to operate with different bandwidth. *The RIT/SRIT should support a scalable bandwidth up to 30 MHz.*

NR NTN

As captured in TS 38.108 [7] and TS 38.101-5 [6], Table 1 shows various transmission bandwidth configurations, including resource block (NRB) as a function of subcarrier spacing (SCS) in kHz and channel bandwidth for FR1.

Table 8.1.1

Transmission bandwidth configuration NRB for FR1

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| SCS (kHz) | 5 MHz | 10 MHz | 15 MHz | 20 MHz | 30 MHz |
| NRB | NRB | NRB | NRB | NRB |
| 15 | 25 | 52 | 79 | 106 | 160 |
| 30 | 11 | 24 | 38 | 51 | 78 |
| 60 | N/A | 11 | 18 | 24 | 38 |

IoT NTN

For NB-IoT NTN satellite access, as captured in TS 36.108 [5] and TS 36.102 [4], Table 2 includes the transmission bandwidth configuration (including channel BW, resource block NRB and subcarrier spacing options), where 15kHz subcarrier spacing is specified for downlink/uplink operation, and 3.75 kHz subcarrier spacing is specified only for uplink operation.

Table 8.1.2

Transmission bandwidth configuration in NB-IoT satellite access channel bandwidth

|  |  |
| --- | --- |
| Channel bandwidth (kHz) | 200 |
| Transmission bandwidth configuration NRB | 1 |
| Transmission bandwidth configuration Ntone, 15 kHz | 12 |
| Transmission bandwidth configuration Ntone, 3.7 5kHz | 48 |

For eMTC NTN satellite access, as captured in TS36.108 and TS 36.102, Table 3 shows the transmission bandwidth configuration (resource block NRB and channel bandwidth).

Table 8.1.3

Transmission bandwidth configuration in eMTC satellite access channel bandwidth

|  |  |
| --- | --- |
| Channel bandwidth (kHz) | 1.4 |
| Transmission bandwidth configuration NRB | 6 |

Conclusions:

Based on the evaluation results above, it is observed that both RIT and SRIT can meet the IMT‑2020 requirement on Bandwidth, i.e. support a scalable bandwidth up to 30 MHz.

## 8.2 Other requirements

### 8.2.1 Support of wide range of services

ITU has defined a requirement on wide range of services to be met by the radio interface technologies of IMT-2020 [1]. These services include high reliability communications via satellite (HRC-s), enhanced mobile broadband via satellite (eMBB-s), and massive machine-type communications via satellite (mMTC-s) usage scenarios.

Based on the evaluation results in this report, it is observed that NR NTN RIT can meet the performance requirements for eMBB-s, HRC-s and mMTC-s; in addition, IoT NTN RIT can meet the performance requirements for mMTC-s.

Therefore, both the 3GPP NTN RIT and SRIT can fulfil the requirement on wide range of services, as captured in the following table.

Table 8.2.1

**Compliance of Service(s)**

| **Service related capabilities within the RIT/SRIT** | **Comments** |
| --- | --- |
| **Support of a wide range of services**  Does the proposal support a wide range of services?:  **☑**YES / 🞎NO | *Both NTN RIT and NTN SRIT can support eMBB-s, mMTC-s and HRC-s usage scenarios* |

### 8.2.2 Supported spectrum band(s)/ranges(s)

The supported spectrum bands and ranges in the RIT(s)/SRIT(s) under evaluation are defined in the following 3GPP technical specifications:

* For IoT-NTN spectrum band(s)/ranges(s): TS 36.102 [4] (UE) and TS 36.108 [5] (BS);
* For NR-NTN spectrum band(s)/ranges(s): TS 38.101-5 [6] (UE) and TS 38.108 [7] (BS).

The defined operating bands are listed in the tables below.

Table 8.2.2,1

**Operating band(s)/ranges(s) for NR NTN**

|  |  |  |  |
| --- | --- | --- | --- |
| **NR**  **Satellite *operating band*** | **Uplink (UL) *operating band* SAN/BS receive / UE transmit**  **FUL,low – FUL,high** | **Downlink (DL) *operating band* SAN/BS transmit / UE receive**  **FDL,low – FDL,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 |

Table 8.2.2,2

**Operating band(s)/ranges(s) for IoT NTN**

|  |  |  |  |
| --- | --- | --- | --- |
| **E-UTRA**  **Satellite *operating band*** | **Uplink (UL) *operating band* SAN/BS receive / UE transmit**  **FUL,low – FUL,high** | **Downlink (DL) *operating band* SAN/BS transmit / UE receive**  **FDL,low – FDL,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 |
| N253 | 1668 MHz – 1675 MHz | 1518 MHz – 1525 MHz | FDD |

The band(s)/ranges(s) defined above include IMT identified bands for the use by the satellite component of IMT, according to provisions in WRC-23 No. 5.388 and Resolution 212 [14], thus comply to the IMT-2020 spectrum requirement, as captured in the following table.

Table 8.2.2,3

**Spectrum Compliance**

|  |  |
| --- | --- |
| **Spectrum requirements** | **Comments** |
| **Spectrum bands**  Is the proposal able to utilize at least one band identified for IMT?: **☑**YES / 🞎NO  Specify in which band(s) the candidate satellite radio interface(s) can be deployed. | *See list of bands above.* |

# 9 Summary and conclusions

This document captures the final evaluation analysis of the ATIS WTSC IMT-2020 SAT IEG related to the satellite technology submissions from 3GPP, i.e. 5G NTN SRIT ([Doc. IMT-2020-SAT/3](https://www.itu.int/md/R19-IMT.2020.SAT-C-0003/en)) and 5G NTN RIT ([Doc. IMT-2020-SAT/4](https://www.itu.int/md/R19-IMT.2020.SAT-C-0004/en)).

The technical performance evaluation and compliance results are summarized in the table below. Evaluation for spectrum and wide range of services is captured in section 8.2.

The evaluation results show that both 3GPP RIT and SRIT submissions fulfil the requirements defined for IMT-2020 Satellite component technology.

Table 9

**Summary of technical performance evaluation results**

| Minimum technical perf. requirement | Category | | | Required value | ATIS IEG evaluation results [range] | Requirement met? | Comments |
| --- | --- | --- | --- | --- | --- | --- | --- |
| Usage scenario | Test environment | Downlink or uplink |
| Peak data rate | eMBB-s | N/A | Uplink | 2 Mbit/s | [2.2-2.6] Mbit/s | Yes | Evaluated for NR NTN (3GPP RIT and SRIT) |
| Downlink | 70 Mbit/s | [97.4-120] Mbit/s | Yes | Evaluated for NR NTN (3GPP RIT and SRIT) |
| Peak spectral efficiency | eMBB-s | N/A | Uplink | 1.5 bit/s/Hz | [1.54-1.82] bit/s/Hz | Yes | Evaluated for NR NTN (3GPP RIT and SRIT) |
| Downlink | 3 bit/s/Hz | [3.2-4] bit/s/Hz | Yes | Evaluated for NR NTN (3GPP RIT and SRIT) |
| User experienced data rate | eMBB-s | Rural | Uplink | 100 kbit/s | [0.13-0.66] Mbit/s | Yes | Evaluated for NR NTN (3GPP RIT and SRIT) |
| Downlink | 1 Mbit/s | [0.92-1.62] Mbit/s | Yes | Evaluated for NR NTN (3GPP RIT and SRIT) |
| 5th percentile user spectral efficiency | eMBB-s | Rural | Uplink | 0.003 bit/s/Hz | [0.004-0.022] bit/s/Hz | Yes | Evaluated for NR NTN (3GPP RIT and SRIT) |
| Downlink | 0.03 bit/s/Hz | [0.03-0.054] bit/s/Hz | Yes | Evaluated for NR NTN (3GPP RIT and SRIT) |
| Average spectral efficiency | eMBB-s | Rural | Uplink | 0.1 bit/s/Hz/TRxP | [0.15-0.27] bit/s/Hz/TRxP | Yes | Evaluated for NR NTN (3GPP RIT and SRIT) |
| Downlink | 0.5 bit/s/Hz/TRxP | [0.49-0.57] bit/s/Hz/TRxP | Yes | Evaluated for NR NTN (3GPP RIT and SRIT) |
| Area traffic capacity | eMBB-s | Rural | Uplink | 1.5 kbit/s/km² | [3.28-4.87] kbit/s/ km² | Yes | Evaluated for NR NTN (3GPP RIT and SRIT) |
| Downlink | 8 kbit/s/km² | [9.34-10.7] kbit/s/ km² | Yes | Evaluated for NR NTN (3GPP RIT and SRIT) |
| User Plane latency | eMBB-s | N/A | N/A | 10 ms | [6.36-6.72] ms | Yes | Evaluated for NR NTN (3GPP RIT and SRIT) |
| Control Plane latency | eMBB-s | N/A | N/A | 40 ms | [22.18-22.36] ms | Yes | Evaluated for NR NTN (3GPP RIT and SRIT) |
| Connection density | mMTC-s | Rural | N/A | 500 devices/km² | NR NTN: [2322~5368] devices/km²  IoT NTN: [1551-1994] devices/km² | Yes | Evaluated for NR NTN (3GPP RIT and SRIT) and IoT NTN (SRIT) |
| Energy efficiency | eMBB-s | N/A | N/A | High sleep ratio and long sleep duration | High sleep ratio and long sleep duration | Yes | Evaluated for NR NTN (3GPP RIT and SRIT) |
| Reliability | HRC-s | Rural | N/A | 99.9% | UL: [99.96~99.99]% UL: [99.97~99.99]% | Yes | Evaluated for NR NTN (3GPP RIT and SRIT) |
| Mobility - Traffic channel link data rate (at 250km/h) | eMBB-s | Rural | N/A | 0.005 bit/s/Hz | [0.07-0.203] bit/s/Hz | Yes | Evaluated for NR NTN (3GPP RIT and SRIT) |
| Mobility interruption time | eMBB-s | N/A | N/A | 50 ms | 0 ms | Yes | Evaluated for NR NTN (3GPP RIT and SRIT) |
| Bandwidth | N/A | N/A | N/A | At least up to and including 30 MHz | 30 MHz | Yes | Evaluated for NR NTN (3GPP RIT and SRIT) |

# Annex 1: Detailed eMBB-s Evaluation Results and Assumptions

**Peak spectral efficiency and data rate**

Company A

For NR, the approximate peak spectral efficiency (when only one component carrier is in use is computed as follows:

=

Wherein

Rmax is the maximum coding rate

is the maximum number of layers

and can take the values 1, 0.8, 0.75, and 0.4

is the numerology (as defined in TS 38.211 [10])

assuming normal cyclic prefix

the maximum Resource Block (RB) allocation in UE supported maximum bandwidth BWwith numerology

Synchronization Signal, PBCH, reference signals, etc. with respect to the total number of REs in the effective bandwidth time product as given by (BW\*14\*

.

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

An overall summary of the evaluation results is captured in Table X, for NR NTN.

Table A.1

Summary of evaluation results for peak spectral efficiency (bit/sec/Hz)

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| Link | SCS [kHz] | BW [MHz/RB] | Peak spectral efficiency [bits/s/Hz] | Requirement [bits/s/Hz] |
| **DL** | 15 | 30 / 160 | 3.2 | 3 |
| **UL** | 15 | 1.44 / 8 | 1.6 | 1.5 |

For NR, the approximate peak data rate (is computed based on the evaluation results of NR satellite access peak spectral efficiency provided in the previous section. Using the analytical method as defined in [1], the peak data rate can be calculated as follows:

=

Wherein

is the maximum bandwidth

is the maximum spectral efficiency.

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

Table A.2

Summary of NR satellite peak data rate (Mbps)

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| Link | SCS [kHz] | BW [MHz/RB] | Peak data rate [Mbps] | Requirement [Mbps] |
| **DL** | 15 | 30 / 160 | 97.4 | 70 |
| **UL** | 15 | 1.44 / 8 | 2.4 | 2 |

Evaluation parameters for NR satellite access peak spectral efficiency and peak data rate are shown in Table Z. The notations in Table Z can be found in the equation provided above.

Table A.3

NR Parameters for peak spectral efficiency and peak data rate evaluation

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| Parameters | DL | UL | | Remarks |
| Max. coding rate *Rmax* | [719/1024] | [490/1024] | |  |
| Max. number of layers | 1 | | |  |
| Highest modulation order | 6 | 4 | | DL: 64QAM  UL: 16QAM |
| Scaling factor of modulation | 1 | | |  |
| Numerology | 0 | | | SCS = 15 kHz |
| Maximum RB allocation | 160 | 8 | | For UL, 8 PRBs out of the full bandwidth is assigned per UE |
| Overhead (OH) | 0.14 | 0.08 | | See 38.306 [13], clause 4.1.2 |
| Frequency | 2.00 GHz | | |  |
| Wavelength | 0.1449 m | | |  |
| Bandwidth | 30 MHz | | 1.44 MHz |  |
| Antenna gain | 30 dBi | | 0 dBi |  |
| EIRP density | 34 dBW/MHz | |  |  |
| EIRP | 48.77 dBW | | ‒7 dBW |  |
| Satellite orbit | LEO-600 | | |  |
| Satellite altitude | 600 km | | |  |
| Elevation angle | 90 degrees | | |  |
| Nadir angle | 0 degrees | | |  |
| Line-of-sight distance | 600 km | | |  |
| Path Loss | 154 dB | | |  |
| Atmospheric Loss | 0 dB | | |  |
| Shadow fading margin | 0 dB | | |  |
| Scintillation loss | 0 dB | | |  |
| Polarization loss | 0 dB | | |  |
| Additional losses | 0 dB | | |  |
| Receive antenna temperature | 290 K | |  |  |
| Noise Figure | 7 dB | |  |  |
| Receive G/T | ‒31.6 dB/K | | 1.1 dB/K |  |
| Subcarrier Spacing (SCS) | 15 kHz | | |  |
| Satellite 3 dB beam width | 4.41 degrees | | |  |

Company B

In contrast to the fully analytical methodology suggested by [1] and consequently adopted by 3GPP, we evaluated peak spectral efficiency and data rate using link-level simulations. We followed, however, the input assumptions representing “ideal conditions”, in particular an elevation angle of 90 degrees, 0 dB atmospheric loss, 0 dB shadow fading margin, 0 dB scintillation loss, 0 dB polarization loss, 0 dB additional losses. In the DL, we used a transmission bandwidth of 160 PRBs. For the UL, a bandwidth of 8 RBs is used.

Table B.1

Parameters for peak spectral efficiency and peak data rate evaluation

|  |  |  |  |
| --- | --- | --- | --- |
| Parameters | DL | UL | Remarks |
| Max. coding rate *Rmax* | [666/1024 - 822/1024] | [434/1024 - 553/1024] |  |
| Max. number of layers | 1 | |  |
| Highest modulation order | 6 | 4 | DL: 64QAM  UL: 16QAM |
| Scaling factor of modulation | 1 | |  |
| Numerology | 0 | | SCS = 15 kHz |
| Maximum RB allocation | 160 | 8 | For UL, 8 PRBs out of the full bandwidth is assigned per UE |
| Overhead (OH) | 0.14 | 0.08 | See 38.306 [13], 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 | |  |

The simulation results are presented in the tables below.

In the DL, the coding rates [666/1024 - 822/1024] with modulation order 6 corresponding to the MCS indices 15 to 18 in Table 5.1.3.1-2: MCS index table 2 for PDSCH (cf. TS 38.214 [12]) are considered, as well as SNR values from 15 dB to 19 dB. PDSCH link performance with and without hybrid-ARQ/link adaptation is characterized. The results corresponding to the analytical 3GPP evaluation (SNR = 17 dB, MCS = 18) are provided in section 5.2 and highlighted in bold below.

DL spectral efficiency

|  |  |  |
| --- | --- | --- |
| SNR = 15 dB | DL spectral efficiency in b/s/Hz | |
| MCS index | Without hybrid-ARQ/link adaptation | With hybrid-ARQ/link adaptation |
| 15 | 3 | 3.56 |
| 16 | 3.19 | 3.56 |
| 17 | 3.38 | 3.56 |
| 18 | 3.39 | 3.56 |

|  |  |  |
| --- | --- | --- |
| SNR = 16 dB | DL spectral efficiency in b/s/Hz | |
| MCS index | Without hybrid-ARQ/link adaptation | With hybrid-ARQ/link adaptation |
| 15 | 3 | 3.78 |
| 16 | 3.20 | 3.78 |
| 17 | 3.45 | 3.78 |
| 18 | 3.59 | 3.78 |

|  |  |  |
| --- | --- | --- |
| SNR = 17 dB | DL spectral efficiency in b/s/Hz | |
| MCS index | Without hybrid-ARQ/link adaptation | With hybrid-ARQ/link adaptation |
| 15 | 3 | 4 |
| 16 | 3.20 | 4 |
| 17 | 3.47 | 4 |
| **18** | **3.66** | **4** |

|  |  |  |
| --- | --- | --- |
| SNR = 18 dB | DL spectral efficiency in b/s/Hz | |
| MCS index | Without hybrid-ARQ/link adaptation | With hybrid-ARQ/link adaptation |
| 15 | 3 | 4.2 |
| 16 | 3.20 | 4.2 |
| 17 | 3.48 | 4.2 |
| 18 | 3.68 | 4.2 |

|  |  |  |
| --- | --- | --- |
| SNR = 19 dB | DL spectral efficiency in b/s/Hz | |
| MCS index | Without hybrid-ARQ/link adaptation | With hybrid-ARQ/link adaptation |
| 15 | 3 | 4.41 |
| 16 | 3.20 | 4.41 |
| 17 | 3.48 | 4.41 |
| 18 | 3.68 | 4.41 |

DL BLER and data rate

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| SNR = 15 dB | Without hybrid-ARQ/link adaptation | | With hybrid-ARQ/link adaptation | |
| MCS index | BLER after initial TX | Data rate in Mbps | BLER after reTX | Data rate in Mbps |
| 15 | 0.0013 | 90.0588 | 0 | 106.9342 |
| 16 | 0.0058 | 95.7057 | 0 | 106.9342 |
| 17 | 0.0278 | 101.5962 | 0 | 106.9342 |
| 18 | 0.0793 | 101.8644 | 0 | 106.9342 |

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| SNR = 16 dB | Without hybrid-ARQ/link adaptation | | With hybrid-ARQ/link adaptation | |
| MCS index | BLER after initial TX | Data rate in Mbps | BLER after reTX | Data rate in Mbps |
| 15 | 2.5000e-04 | 90.1535 | 0 | 113.3782 |
| 16 | 0.0013 | 96.1437 | 0 | 113.3782 |
| 17 | 0.0083 | 103.6339 | 0 | 113.3782 |
| 18 | 0.0271 | 107.6394 | 0 | 113.3782 |

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| SNR = 17 dB | Without hybrid-ARQ/link adaptation | | With hybrid-ARQ/link adaptation | |
| MCS index | BLER after initial TX | Data rate in Mbps | BLER after reTX | Data rate in Mbps |
| 15 | 0 | 90.1760 | 0 | 119.9926 |
| 16 | 0 | 96.2640 | 0 | 119.9926 |
| 17 | 0.0016 | 104.3288 | 0 | 119.9926 |
| **18** | **0.0073** | **109.8189** | **0** | **119.9926** |

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| SNR = 18 dB | Without hybrid-ARQ/link adaptation | | With hybrid-ARQ/link adaptation | |
| MCS index | BLER after initial TX | Data rate in Mbps | BLER after reTX | Data rate in Mbps |
| 15 | 0 | 90.1760 | 0 | 126.2255 |
| 16 | 0 | 96.2640 | 0 | 126.2255 |
| 17 | 2.5e-04 | 104.4699 | 0 | 126.2255 |
| 18 | 0.0015 | 110.4550 | 0 | 126.2255 |

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| SNR = 19 dB | Without hybrid-ARQ/link adaptation | | With hybrid-ARQ/link adaptation | |
| MCS index | BLER after initial TX | Data rate in Mbps | BLER after reTX | Data rate in Mbps |
| 15 | 0 | 90.1760 | 0 | 132.5451 |
| 16 | 0 | 96.2640 | 0 | 132.5451 |
| 17 | 0 | 104.4960 | 0 | 132.5451 |
| 18 | 2e-4 | 110.6099 | 0 | 132.5451 |

In the UL, the coding rates [434/1 024 - 553/1 024] with modulation order 4 corresponding to the MCS indices 12 to 14 in Table 6.1.4.1-1: MCS index table for PUSCH with transform precoding and 64QAM (cf. TS 38.214 [12]) are considered, as well as SNR values from 5 dB to 8 dB. PUSCH link performance with and without hybrid-ARQ/link adaptation is characterized. The results corresponding to the analytical 3GPP evaluation (SNR = 7 dB, MCS = 14) are provided in section 5.2 and highlighted in bold below.

UL spectral efficiency

|  |  |  |
| --- | --- | --- |
| SNR = 5 dB | UL spectral efficiency in b/s/Hz | |
| MCS index | Without hybrid-ARQ/link adaptation | With hybrid-ARQ/link adaptation |
| 12 | 1.20 | 1.49 |
| 13 | 1.22 | 1.49 |
| 14 | 1.14 | 1.49 |

|  |  |  |
| --- | --- | --- |
| SNR = 6 dB | UL spectral efficiency in b/s/Hz | |
| MCS index | Without hybrid-ARQ/link adaptation | With hybrid-ARQ/link adaptation |
| 12 | 1.3 | 1.65 |
| 13 | 1.36 | 1.65 |
| 14 | 1.39 | 1.65 |

|  |  |  |
| --- | --- | --- |
| SNR = 7 dB | UL spectral efficiency in b/s/Hz | |
| MCS index | Without hybrid-ARQ/link adaptation | With hybrid-ARQ/link adaptation |
| 12 | 1.35 | 1.82 |
| 13 | 1.45 | 1.82 |
| 14 | 1.54 | 1.82 |

|  |  |  |
| --- | --- | --- |
| SNR = 8 dB | UL spectral efficiency in b/s/Hz | |
| MCS index | Without hybrid-ARQ/link adaptation | With hybrid-ARQ/link adaptation |
| 12 | 1.38 | 2 |
| 13 | 1.49 | 2 |
| 14 | 1.62 | 2 |

UL BLER and data rate

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| SNR = 5 dB | Without hybrid-ARQ/link adaptation | | With hybrid-ARQ/link adaptation | |
| MCS index | BLER after initial TX | Data rate in Mbps | BLER after reTX | Data rate in Mbps |
| 12 | 0.1402 | 1.7403 | 0 | 2.1488 |
| 13 | 0.2063 | 1.7588 | 0 | 2.1488 |
| 14 | 0.1148 | 1.6435 | 0 | 2.1488 |

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| SNR = 6 dB | Without hybrid-ARQ/link adaptation | | With hybrid-ARQ/link adaptation | |
| MCS index | BLER after initial TX | Data rate in Mbps | BLER after reTX | Data rate in Mbps |
| 12 | 0.0724 | 1.8775 | 0 | 2.3797 |
| 13 | 0.1141 | 1.9631 | 0 | 2.3797 |
| 14 | 0.0945 | 2.0082 | 0 | 2.3797 |

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| SNR = 7 dB | Without hybrid-ARQ/link adaptation | | With hybrid-ARQ/link adaptation | |
| MCS index | BLER after initial TX | Data rate in Mbps | BLER after reTX | Data rate in Mbps |
| 12 | 0.0357 | 1.9518 | 0 | 2.6219 |
| 13 | 0.0579 | 2.0878 | 0 | 2.6219 |
| **14** | **0.0757** | **2.2213** | **0** | **2.6219** |

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| SNR = 8 dB | Without hybrid-ARQ/link adaptation | | With hybrid-ARQ/link adaptation | |
| MCS index | BLER after initial TX | Data rate in Mbps | BLER after reTX | Data rate in Mbps |
| 12 | 0.0169 | 1.9898 | 0 | 2.8742 |
| 13 | 0.0280 | 2.1540 | 0 | 2.8742 |
| 14 | 0.0587 | 2.3448 | 0 | 2.8742 |

**5th Percentile and Average Spectral Efficiency**

Company A

For the evaluation of 5th percentile user spectral efficiency, user experienced data rate, average spectral efficiency, and area traffic capacity, we followed the steps outlined in ITU-R M.2514 [1] and M.2412 [2] reports. We only considered full-buffer traffic for the system-level simulation (SLS).

Main parameters are shown in Table 1.

* For DL, we assumed 1Tx, 2 Rx and 1Tx, 4 Rx transmission with cross polarized UE antennas. For UL, we assumed 1 Tx, 1 Rx transmission.
* For UL, the scheduling scheduling granularity was set to 10 RBs.
* For calculation of spectral efficiency, the channel bandwidth was set to 30 MHz, using FRF 3.

Table A.1

Parameters for system-level simulation

|  |  |
| --- | --- |
| Satellite orbit | LEO-600 |
| Satellite altitude | 600 km |
| Satellite antenna pattern | Section 6.4.1 in [1] |
| Satellite antenna polarization | Circular |
| Satellite antenna number | 1 Tx / 1 Rx per beam |
| 3 dB beam width | 4.41 degrees |
| Satellite EIRP density | 34 dBW/MHz |
| Satellite antenna gain | 30 dBi |
| Satellite G/T | 1.1 dB/K |
| Central beam center elevation | 90 deg |
| UE anntenna type | Handheld, (1,1,2) with omni-directional antenna element |
| UE antenna polarization | Linear: +/- 45deg X-pol |
| UE Rx Antenna gain | 0 dBi |
| UE antenna temperature | 290 K |
| UE noise figure | 7 dB |
| FRF | 1 or 3 |
| Carrier frequency | 2 GHz |
| SCS | 15 kHz |
| Channel bandwidth | 30 MHz ( 10MHz for FRF3 ) |
| Scenario | Rural-eMBB-s |
| UE deployment | 100% outdoor and uniformly distributed over the area |
| LOS condition | 100% LOS |
| Spot beam pattern and frequency reuse factor | Hexagonal pattern, 19 inner beams,  Total beams: 61 beams for FRF=1,  127 beams for FRF=3. |
| UE density | 10 UEs per beam |
| UE mobility | 0 (Stationary) |
| Satellite mobility | 0 (Doppler spread is assumed to be compensated) |
| Large scale channel model | Large scale model of Section 6.6 in 38.811 [8] |
| Small scale channel model | Frequency selective fading model of Section 6.7.2 in 38.811 [8] |
| Handover margin | 0dB (handover was not simulated) |
| UE attachment | RSRP |
| Traffic model | Full-buffer |
| Scheduling scheme | PF and SU-MIMO |
| Receiver type | MMSE-IRC |
| Channel estimation | Realistic |
| Frequency offset | 0ppm |
| Frequency drift | 0ppm |
| DL CSI measurement | CQI only (1 layer / 1-port CSI-RS) |
| PRB bundling | Wideband |
| Codeword (CW) | SCW |
| Transmission scheme | One layer |
| Frame structure | FDD |
| Overhead | 0.14 (same as for peak data rate calculation) |

The results, for DL and UL, are presented in the Tables below.

Table A.2

Evaluation results for eMBB DL Spectral efficiency

|  |  |  |  |
| --- | --- | --- | --- |
| Number of UE  antennas | Frequency reuse factor | TPR | Reported Value with scintillation loss |
| 2 | FRF = 3 | Average [bit/s/Hz/TRxP] | 0.4914 |
| 5th percentile [bit/s/Hz] | 0.0307 |
| 4 | FRF = 3 | Average [bit/s/Hz/TRxP] | 0.5054 |
| 5th percentile [bit/s/Hz] | 0.0337 |

Table A.3

Evaluation results for eMBB UL Spectral efficiency

|  |  |  |  |
| --- | --- | --- | --- |
| Number of UE  antennas | Frequency reuse factor | Requirement | Reported Value |
| 1 | FRF = 3 | Average [bit/s/Hz/TRxP] | 0.155 |
| 5th percentile [bit/s/Hz] | 0.004 |

Company B

For the evaluation of 5th percentile user spectral efficiency, user experienced data rate, average spectral efficiency, and area traffic capacity, we followed the procedures outlined in M.2514 [1] and M.2412 [2]. Concerning simulation assumptions, we followed the guidelines provided in section 8 of M.2514 [1]. complemented by assumptions captured in 3GPP TR 38.811 [8] and 38.821 [9].

Main assumptions are captured below.

|  |  |
| --- | --- |
| Sat altitude [km] | 600 |
| Sat elevation angle [deg] | 90 |
| HPBW [deg] | 4.41 |
| Spot beam pattern | 19 hexagonal spot beams for statistics 2 additional tiers of interferers |
| UE deployment | Exactly 10 per beam area |
| Outdoor probability | 1 |
| UE density | 10 per beam |
| Cell selection method | RSRP |
| UE mobility | stationary |
| UE antenna height [m] | 1.5 |
| EIRP density [dBW/MHz] | 34 |
| Sat antenna gain [dB] | 30 |
| Satellite G/T [dB/K] | 1.1 |
| Carrier frequency [GHz] | 2 |
| Channel BW [MHz] | 30 |
| SCS [kHz] | 15 |
| DL number of PRBs | 160 for FRF=1 / 52 for FRF=3 |
| Number of Polarizations | 1 |
| Freq. Reuse (FRF) | 1 and 3 |
| Traffic model | Full buffer |
| Terminal Type | Handheld |
| UE antenna gain [dB] | 0 |
| UE noise figure [dB] | 7 |
| UL number of PRBs | 16 for FRF=1 / 5 for FRF=3 |
| UE Tx power [dBm] | 23 |
| Polarization | Linear 45 deg |
| Antenna Temperature [K] | 290 |
| Scintillation loss [dB] | 0 |
| Polarization loss [dB] | 0 |
| Additional losses [dB] | 0 |

The results were obtained from a dynamic system level simulator configured with a full buffer traffic model. Are the results for FRF=1 and FRF=3.

5th percentile spectral efficiency

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
|  | IMT-2020 target | 3GPP results | Evaluation results | |
| FRF=1 | FRF=3 |
| DL | 0.03 | 0.029-0.047 | 0.033 | 0.054 |
| UL | 0.003 | 0.006-0.010 | 0.015 | 0.022 |

Average spectral efficiency

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
|  | IMT-2020 target | 3GPP results | Evaluation results | |
| FRF=1 | FRF=3 |
| DL | 0.5 | 0.562-0.783 | 0.527 | 0.569 |
| UL | 0.1 | 0.145-0.233 | 0.248 | 0.275 |

The 5th percentile spectral efficiency presented in section 5.3 was calculated based on the reported user experience data rate and a system bandwidth of 30 MHz.

**User Experienced Data Rate**

Company A

See Spectral efficiency assumptions. Results are shown in the table below.

|  |  |  |  |
| --- | --- | --- | --- |
| User experienced data rate | Number of UE  antennas | Frequency reuse factor | Reported Value |
| DL | 2 | FRF = 3 | 0.92 |
| 4 | FRF = 3 | 1.011 |
| UL | 1 | FRF = 3 | 0.133 |

Company B

See spectral efficiency assumptions. Results are calculated based on the reported 5th percentile spectral efficiencies and a system bandwidth of 30 MHz and are shown in the table below.

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
|  | IMT-2020 target | 3GPP results | Evaluation results | |
| FRF=1 | FRF=3 |
| DL | 1 | 0.85-1.43 | 0.99 | 1.62 |
| UL | 0.1 | 0.13-0.28 | 0.45 | 0.66 |

**Area Traffic Capacity**

Company A

See Spectral efficiency assumptions. Values of area traffic capacity are reported in the table below.

|  |  |  |  |
| --- | --- | --- | --- |
| Area traffic Capacity | Number of UE  antennas | Frequency reuse factor | Reported Value |
| DL | 2 | FRF = 1 | 8.0989 |
| FRF = 3 | 10.419 |
| 4 | FRF = 3 | 10.707 |
| UL | 1 | FRF = 1 | 1.6537 |
| FRF = 3 | 3.2862 |

Company B

See spectral efficiency assumptions. Under the assumption of hexagonal cells and a 50 km cell diameter, a cell covers an area of approximately 1 625 km2. Results based on this assumption for the cell size, a useful bandwidth per cell of 28.8 MHz and the reported average spectral efficiencies are shown in the table below.

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
|  | IMT-2020 target | 3GPP results | Evaluation results | |
| FRF=1 | FRF=3 |
| DL | 8 | 11.30-16.60 | 9.34 | 10.08 |
| UL | 1.5 | 3.06-4.87 | 4.39 | 4.87 |

**Mobility**

**Company A**

The parameters that are used for LLS are presented in the Table 1 below.

Table A1

LLS parameters for eMBB-s Mobility

|  |  |
| --- | --- |
| Physical channel | PUSCH |
| Simulation bandwidth (PRB) | 5 RBs (Consistent with SLS BW) |
| Number of users in simulation | 1 |
| Link-level Channel model | NTN TDL-C Rural |
| DMRS config | 2 symbol DMRS |
| Antenna configuration at Satellite | 1 Rx |
| Antenna configuration at UE | 1 Tx |
| Transmission mode | SISO |
| Transmission rank | 1 |
| TBS | Based on MCS Sweep |
| Modulation order | Based on MCS Sweep |
| Number of repetitions | [1,2,4,8] |
| Channel estimation | LMMSE |
| Channel coding scheme | LDPC |
| Doppler spread | 463 Hz |

The maximum achievable spectral efficiency with its reliability has been reported in Table 2. Note that the spectral efficiency is the same as normalized traffic channel link data rate.

Table A2

Performance evaluation of mobility

|  |  |
| --- | --- |
| Parameter | Value |
| FRF | 3 |
| 50 percentile SINR | 0.95 dB |
| System Bandwidth (W) | 0.9 MHz (5 PRBs) |
| Packet Error Ratio | 0.62% (requirement: <1%) |
| Normalized traffic channel link data rate | 0.203 bps/Hz |

**Company B**

The parameters that are used for LLS are presented in the Table 1 below.

Table B1

LLS parameters for eMBB-s Mobility

|  |  |
| --- | --- |
| Physical channel | PUSCH |
| Simulation bandwidth (PRB) | Consistent with SLS BW |
| Number of users in simulation | 1 |
| Link-level Channel model | NTN TDL-C Rural |
| DMRS config | 2 symbol DMRS |
| Antenna configuration at Satellite | 1 Rx |
| Antenna configuration at UE | 1 Tx |
| Transmission mode | SISO |
| Transmission rank | 1 |
| TBS | Based on MCS Sweep |
| Modulation order | Based on MCS Sweep |
| Number of repetitions | 1 |
| Channel estimation | LMMSE |
| Channel coding scheme | LDPC |
| Doppler spread | Ideal |

We simulate both FRF=1 and FRF=3. The maximum achievable spectral efficiency with its reliability has been reported in Table 2. Note that the spectral efficiency is the same as normalized traffic channel link data rate.

Table B2

Performance evaluation of mobility

|  |  |  |
| --- | --- | --- |
| Parameter | Value | |
| FRF | 1 | 3 |
| 50 percentile SINR | -2.3 dB | 5.3 dB |
| System Bandwidth (W) | 3 MHz | 1 MHz |
| Packet Error Ratio | 0.18% | 0.33% |
| Normalized traffic channel link data rate | 0.07 bps/Hz | 0.14 bps/Hz |

**Latency**

User Plane Latency

The evaluation of NR satellite access user plane latency is based on the following assumptions:

* *It is assumed that the packet arrives at any time of any OFDM symbol. To capture the worst-case scenario, 1 symbol length is added 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) assumes slot-based scheduling with 14 OFDM Symbol length slot.*
* *Resource mapping type A is considered, which impact the start timing of a transmission. Details on resource mapping mechanism can be found in TS 38.214 [12].*
* *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.*
* *UE processing capability 1 and 2 are considered.*
* *The subcarrier spacing is 15 kHz.*

The calculation of the user plane latency in downlink direction is provided in Table 1 and 2 for UE capability 1 and 2, respectively, based on the above assumptions.

Table 1

DL user plane latency for NR satellite access for LEO satellite at 600 km altitude (UE processing capability 1)

|  |  |  |
| --- | --- | --- |
| *Step* | *Description* | *Duration (ms)* |
| *1* | *Initial symbol alignment* | *0.0714* |
| *2* | *gNB processing delay (the time interval between data arrival and packet generation): tBS,tx=Tproc,2/2, where Tproc,2 is defined in TS 36.214 (Section 6.4) where N2=10, d2,1=0, d2=0, d2,2=0, Text=0, Tswitch=0, Tc=5.09e-10, and k=64.* | *0.3568* |
| *3* | *Downlink frame alignment (transmission alignment, the time interval between packet generation and the next Tx opportunity):TFA, length of one slot.* | *1* |
| *4* | *TTI (Transmission Time Interval) for downlink data packet transmission: tDL\_duration, length of one slot (14 OFDM symbol length)* | *1* |
| *5* | *One way propagation (BS to Satellite to UE): tprop=RTD/2, where RTD is the minimum round-trip delay for LEO satellite at 600 km altitude, and transparent payload.* | *4.003* |
| *6* | *UE processing delay (the time interval between PDSCH reception and decoding of the data):tUE,rx = Tproc,1/2, where Tproc,1 is defined in TS 36.214 (Section 5.3) where N1=8, d1,1=0, d2=0, Text=0, Tc=5.09e-10, and k=64.* | *0.2854* |
| *7* | *Total one-way user plane latency for downlink: TDL = tBS,tx + tFA + tDL\_duration + tprop + tUE,rx* | *6.7164* |

Table 2

DL user plane latency for NR satellite access for LEO satellite at 600 km altitude (UE processing capability 2)

|  |  |  |
| --- | --- | --- |
| *Step* | *Description* | *Duration (ms)* |
| *1* | *Initial symbol alignment* | *0.0714* |
| *2* | *gNB processing delay (the time interval between data arrival and packet generation): tBS,tx=Tproc,2/2, where Tproc,2 is defined in TS 36.214 (Section 6.4) where N2=5, d2,1=0, d2=0, d2,2=0, Text=0, Tswitch=0, Tc=5.09e-10, and k=64.* | *0.1784* |
| *3* | *Downlink frame alignment (transmission alignment, the time interval between packet generation and the next Tx opportunity):TFA, length of one slot.* | *1* |
| *4* | *TTI (Transmission Time Interval) for downlink data packet transmission: tDL\_duration, length of one slot (14 OFDM symbol length)* | *1* |
| *5* | *One way propagation (BS to Satellite to UE): tprop=RTD/2, where RTD is the minimum round-trip delay for LEO satellite at 600 km altitude, and transparent payload.* | *4.003* |
| *6* | *UE processing delay (the time interval between PDSCH reception and decoding of the data):tUE,rx = Tproc,1/2, where Tproc,1 is defined in TS 36.214 (Section 5.3) where N1=3, d1,1=0, d2=0, Text=0, Tc=5.09e-10, and k=64.* | *0.1070* |
| *7* | *Total one-way user plane latency for downlink: TDL = tBS,tx + tFA + tDL\_duration + tprop + tUE,rx* | *6.3596* |

The calculation of the user plane latency in uplink direction is provided in Table 3 and Table 4 for UE capability 1 and 2, respectively, based on the assumptions given above.

Table 3

UL user plane latency for NR satellite access for LEO satellite at 600 km altitude (UE processing capability 1)

|  |  |  |
| --- | --- | --- |
| *Step* | *Description* | *Duration (ms)* |
| *1* | *Initial symbol alignment* | *0.0714* |
| *2* | *UE processing delay (the time interval between data arrival and packet generation): tUE,tx=Tproc,2/2, where Tproc,2 is defined in TS 36.214 (Section 6.4) where N2=10, d2,1=0, d2=0, d2,2=0, Text=0, Tswitch=0, Tc=5.09e-10, and k=64.* | *0.3568* |
| *3* | *Uplink frame alignment (transmission alignment, the time interval between packet generation and the next Tx opportunity):TFA, length of one slot.* | *1* |
| *4* | *TTI (Transmission Time Interval) for uplink data packet transmission: tUL\_duration, length of one slot (14 OFDM symbol length)* | *1* |
| *5* | *One way propagation (UE to Satellite to gNB): tprop=RTD/2, where RTD is the minimum round-trip delay for LEO satellite at 600 km altitude, and transparent payload.* | *4.003* |
| *6* | *gNB processing delay (the time interval between PDSCH reception and decoding of the data):tBS,rx = Tproc,1/2, where Tproc,1 is defined in TS 36.214 (Section 5.3) where N1=8, d1,1=0, d2=0, Text=0, Tc=5.09e-10, and k=64.* | *0.2854* |
| *7* | *Total one-way user plane latency for uplink: TUL = tUE,tx + tFA + tUL\_duration + tprop + tBS,rx* | *6.7164* |

Table 4

UL user plane latency for NR satellite access for LEO satellite at 600 km altitude (UE processing capability 2)

|  |  |  |
| --- | --- | --- |
| *Step* | *Description* | *Duration (ms)* |
| *1* | *Initial symbol alignment* | *0.0714* |
| *2* | *UE processing delay (the time interval between data arrival and packet generation): tUE,tx=Tproc,2/2, where Tproc,2 is defined in TS 36.214 (Section 6.4) where N2=5, d2,1=0, d2=0, d2,2=0, Text=0, Tswitch=0, Tc=5.09e-10, and k=64.* | *0.1784* |
| *3* | *Uplink frame alignment (transmission alignment, the time interval between packet generation and the next Tx opportunity):TFA, length of one slot.* | *1* |
| *4* | *TTI (Transmission Time Interval) for uplink data packet transmission: tUL\_duration, length of one slot (14 OFDM symbol length)* | *1* |
| *5* | *One way propagation (UE to Satellite to gNB): tprop=RTD/2, where RTD is the minimum round-trip delay for LEO satellite at 600 km altitude, and transparent payload.* | *4.003* |
| *6* | *gNB processing delay (the time interval between PDSCH reception and decoding of the data):tBS,rx = Tproc,1/2, where Tproc,1 is defined in TS 36.214 (Section 5.3) where N1=3, d1,1=0, d2=0, Text=0, Tc=5.09e-10, and k=64.* | *0.1070* |
| *7* | *Total one-way user plane latency for uplink: TUL = tUE,tx + tFA + tUL\_duration + tprop + tBS,rx* | *6.3596* |

Contol Plane Latency

For 5G NR satellite access, control plane latency is evaluated from RRC\_INACTIVE state to RRC\_CONNECTED state. The evaluation of NR satellite access control plane latency is based on the following assumptions:

* *Resource mapping type A is considered, which impact the start timing of a transmission. Details on resource mapping mechanism can be found in TS 38.214 [12].*
* *The evaluation is for uplink data transfer.*
* *It is assumed an initial error probability of 0.*
* *It is assumed that satellite on-board delay can be considered negligible.*
* *UE processing capability 1 and 2 are considered.*
* *The subcarrier spacing is 15 kHz.*
* *2-step random access is used.*

The calculation of the control plane latency is provided in Table 5 and 6 for UE capability 1 and 2, respectively, based on the above assumptions.

Table 5

Control plane latency for NR satellite access for LEO satellite at 600 km altitude (UE processing capability 1)

|  |  |  |
| --- | --- | --- |
| *Step* | *Description* | *Duration (ms)* |
| *1* | *Delay due to RACH scheduling period. The transition from a most “battery efficient” state has not started, and as a result this step is not relevant for the latency.* | *0* |
| *2* | *UE processing delay for L1 encoding of RRC Resume Request: tUE,tx=Tproc,2/2, where Tproc,2 is defined in TS 36.214 (Section 6.4) where N2=10, d2,1=0, d2=0, d2,2=0, Text=0, Tswitch=0, Tc=5.09e-10, and k=64.* | *0.3568* |
| *3* | *Transmission of RACH preamble (length of the preamble according to the PRACH format as specified in TS 38.211 [10]): ttx,preamble* | *1* |
| *4* | *Transmission interval (length of the interval between PRACH and PUSCH transmissions as specified in TS 38.213 [11]): tPUSCH\_offset* | *1* |
| *5* | *Transmission of PUSCH payload (RRCResumeRequest): tx,PUSCH* | *1* |
| *6* | *One way propagation (UE to Satellite to gNB): tprop=RTD/2, where RTD is the minimum round-trip delay for LEO satellite at 600 km altitude, and transparent payload.* | *4.003* |
| *7* | *MsgA detection and processing delay in gNB (preamble, L2, and RRC): tBS,rx* | *3* |
| *8* | *Transmission of MsgB (RA response): ttx,MsgB* | *1* |
| *9* | *One way propagation (gNB to Satellite to UE): tprop=RTD/2, where RTD is the minimum round-trip delay for LEO satellite at 600 km altitude, and transparent payload.* | *4.003* |
| *9* | *UE processing delay of RRC Resume, including RA Response: tUE,rx* | *7* |
| *10* | *Transmission of RRC Resume Complete and data* | *0* |
| *11* | *Total control plane latency: T= tUE,tx + ttx,preamble + tPUSCH\_offset + ttx,PUSCH+ tprop + tBS,rx+ ttx,MsgB+ tprop + tUE,rx* | *22.3623* |

Table 6

Control plane latency for NR satellite access for LEO satellite at 600 km altitude (UE processing capability 2)

|  |  |  |
| --- | --- | --- |
| *Step* | *Description* | *Duration (ms)* |
| *1* | *Delay due to RACH scheduling period. The transition from a most “battery efficient” state has not started, and as a result this step is not relevant for the latency.* | *0* |
| *2* | *UE processing delay for L1 encoding of RRC Resume Request: tUE,tx=Tproc,2/2, where Tproc,2 is defined in TS 36.214 (Section 6.4) where N2=5, d2,1=0, d2=0, d2,2=0, Text=0, Tswitch=0, Tc=5.09e-10, and k=64.* | *0.1784* |
| *3* | *Transmission of RACH preamble (length of the preamble according to the PRACH format as specified in TS 38.211 [10]): ttx,preamble* | *1* |
| *4* | *Transmission interval (length of the interval between PRACH and PUSCH transmissions as specified in TS 38.213 [11]): tPUSCH\_offset* | *1* |
| *5* | *Transmission of PUSCH payload (RRCResumeRequest): tx,PUSCH* | *1* |
| *6* | *One way propagation (UE to Satellite to gNB): tprop=RTD/2, where RTD is the minimum round-trip delay for LEO satellite at 600 km altitude, and transparent payload.* | *4.003* |
| *7* | *MsgA detection and processing delay in gNB (preamble, L2, and RRC): tBS,rx* | *3* |
| *8* | *Transmission of MsgB (RA response): ttx,MsgB* | *1* |
| *9* | *One way propagation (gNB to Satellite to UE): tprop=RTD/2, where RTD is the minimum round-trip delay for LEO satellite at 600 km altitude, and transparent payload.* | *4.003* |
| *9* | *UE processing delay of RRC Resume, including RA Response: tUE,rx* | *7* |
| *10* | *Transmission of RRC Resume Complete and data* | *0* |
| *11* | *Total control plane latency: T= tUE,tx + ttx,preamble + tPUSCH\_offset + ttx,PUSCH+ tprop + tBS,rx+ ttx,MsgB+ tprop + tUE,rx* | *22.1839* |

# Annex 2: Detailed HRC-s Evaluation Results and Assumptions

**Company A**

The parameters for LLS are reported in Table 1.

We consider 16 repetitions for UL. These repetitions span a total duration of 36 ms. For the first 8 ms, PUSCH with RV 0 is transmitted over 8 slots of TBoMS. Then, there is a gap of 20ms to leverage time diversity. After that, PUSCH with RV 2 is transmitted with another 8 slots of TBoMS.

Table A1

Parameters for LLS Reliability for NR UL and DL

|  |  |  |
| --- | --- | --- |
|  | NR Uplink | NR Downlink |
| Physical channel | PUSCH | PDSCH |
| SCS | 15 kHz | 15 kHz |
| Simulation bandwidth (PRBs) | 5 RBs | 8 PRBs for 64 QAM MCS Table, 30 RBs for low SE MCS Table |
| Number of users in simulation | 1 | 1 |
| Link-level Channel model | NTN TDL-C Rural | NTN TDL-C Rural |
| DMRS config | 2 DMRS per slot | 2 symbol DMRS |
| Antenna configuration at Satellite | 1Rx | 1Tx |
| Antenna configuration at UE | 1Tx | 2 Rx |
| Transmission mode | SISO | SISO |
| Transmission rank | 1 | 1 |
| TBS | 256 | 256 |
| Modulation order | QPSK | QPSK |
| Number of repetitions | 16 (8 TBoMS + 20 ms + 8 TBoMS) | 1 |
| Channel estimation | LMMSE | LMMSE |
| Channel coding scheme | LDPC | LDPC |
| Doppler spread | 5 Hz | 5 Hz |
| MCS | MCS 2 from Table 6.1.4.1-2 of [3] | MCS 0 |

The results for UL and DL reliability after LLS have been reported in Table 2.

Table A2

Performance evaluation of reliability

|  |  |  |
| --- | --- | --- |
| Parameter | Mode | |
| Uplink | Downlink |
| FRF | 3 | 3 |
| 5 percentile SINR | ‒0.63 dB | 6.79 dB |
| Scheduled Bandwidth | 0.9 MHz (5 PRBs) | 8 PRBs, 30 PRBs |
| Reliability | 99.96 % | 99.97 %, 99.99% |
| Connection Time Duration | 36 ms | 1 ms |

**Company B**

The parameters for LLS are reported in Table 1. We consider a maximum of 4 retransmissions, resulting in a maximum connection duration of 32.2 ms.

Table B1

Parameters for LLS Reliability for NR UL and DL

|  |  |  |
| --- | --- | --- |
|  | NR Uplink | NR Downlink |
| Physical channel | PUSCH | PDSCH |
| SCS | 15 kHz | 15 kHz |
| Simulation bandwidth (PRBs) | Consistent with SLS BW | Consistent with SLS BW |
| Number of users in simulation | 1 | 1 |
| Link-level Channel model | NTN TDL-C Rural | NTN TDL-C Rural |
| DMRS config | 2 DMRS per slot | 2 symbol DMRS |
| Antenna configuration at Satellite | 1Rx | 1Tx |
| Antenna configuration at UE | 1Tx | 1Rx |
| Transmission mode | SISO | SISO |
| Transmission rank | 1 | 1 |
| TBS | 256 | 256 |
| Modulation order | QPSK | QPSK |
| Number of repetitions | 1 | 1 |
| Channel estimation | LMMSE | LMMSE |
| Channel coding scheme | LDPC | LDPC |
| Doppler spread | 5 Hz | 5 Hz |
| MCS | Based on MCS Table 6.1.4.1-1 of [3] | Based on MCS Table 5.1.3.1-1 of [3] |

In our simulations, the initial BLER is 10.0% in the DL and 10.4% in the UL. The resulting reliability is 99.990% in the DL and 99.989% in the UL, at a connection duration of 32.2 ms.

# Annex 3: Detailed mMTC-s Evaluation Results and Assumptions

**Company A**

For connection density evaluations, we follow the procedure and assumptions mentioned in M.2514 [1] and M.2412 [2], for full buffer scenario.

1) Evaluation assumptions and results for NR NTN

The LLS parameters are provided in Table 1 below.

Table A1

LLS parameters for NR-NTN mMTC evaluations

|  |  |
| --- | --- |
| Physical channel | PUSCH |
| Simulation bandwidth (=bandwidth allocated per UE) | 1 PRB |
| SCS | 15 kHz |
| Link-level Channel model | NTN TDL-C Rural |
| Antenna configuration at Satellite | 1Rx |
| Antenna configuration at UE | 1Tx |
| Transmission mode | SISO |
| Transmission rank | 1 |
| TBS | Based on MCS Sweep |
| Modulation order | Based on MCS Sweep |
| Number of repetitions | 1,2,4,8 (TBoMS) |
| Channel estimation | LMMSE |
| Channel coding scheme | LDPC |
| Doppler spread | 5 Hz |
| UL DMRS config | DMRS per slot |

Based on different inter-packet arrival times and system bandwidths, we report the connection density in Table 2.

Table A2

Performance metrics for NR-NTN mMTC

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| Parameter | Values | | | |
| For FRF = 1 | | For FRF = 3 | |
| Service Profile | Full buffer | | Full buffer | |
| 1 percentile pre-processing SINR | ‒5.08 dB | | 3.27 dB | |
| System Bandwidth (W) | 10 MHz, 180 KHz | | 10 MHz, 180 KHz | |
| 99th Percentile Delay | 0.0088 s | | 0.0044 s | |
| Inter-packet arrival time | 1 message/2 hours/device | 1 message/day/device | 1 message/2 hours/device | 1 message/day/device |
| Connection Density | 41,513 Devices/km2,  747 Devices/ km2 | 498,158 Devices/ km2, 8 966 Devices/km2 | 129,041 Devices/ km2 ,  2 322 Devices/ km2 | 1,548,494 Devices/km2,  27,972 Devices/km2 |

2) Evaluation assumptions and results for NB-IoT NTN

The LLS parameters are provided in the Table 3 below.

Table A3

LLS parameters for NB-IoT NTN mMTC evaluations

|  |  |
| --- | --- |
| Physical channel | NPUSCH |
| Simulation bandwidth | Single Tone |
| SCS | 15 kHz |
| Number of users in simulation | 1 |
| Link-level Channel model | NTN TDL-C Rural |
| Antenna configuration at Satellite | 1 Rx |
| Antenna configuration at UE | 1 Tx |
| Transmission mode | SISO |
| Transmission rank | 1 |
| TBS | 256 |
| Modulation order | QPSK-π/4 |
| Number of Resource units | 2,3,4,5,6,8,10 |
| Number of repetitions | 1,2,4,8,16 |
| Channel estimation | LMMSE |
| Channel coding scheme | Turbo code |
| Doppler spread | 5 Hz |
| UL DMRS config | Single DMRS per slot [3] |

The connection density is reported in Table 4.

Table A4

Performance metrics and results for NTN NB-IoT

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| Parameter | Values | | | |
| For FRF = 1 | | For FRF = 3 | |
| Service Profile | Full buffer | | Full buffer | |
| 1 percentile pre-processing SINR | ‒4.83 dB | | 5.72 dB | |
| System Bandwidth (W) | 0.18 MHz | | 0.18 MHz | |
| 99th Percentile Delay | 0.265 s | | 0.035 s | |
| Inter-packet arrival time | 1 message/ 2 hours/device | 1 message/day/device | 1 message/ 2 hours/device | 1 message/day/device |
| Connection Density | 506 Devices/ km2 | 6 072 Devices/ km2 | 1 994 Devices/ km2 | 23,928 Devices/km2 |

3) Evaluation assumptions and results for eMTC NTN

The LLS parameters have been provided in Table 5 below.

Table A5

LLS parameters for eMTC NTN mMTC evaluations

|  |  |
| --- | --- |
| Physical channel | PUSCH |
| Simulation bandwidth | 1 PRB |
| SCS | 15 kHz |
| Number of users in simulation | 1 |
| Link-level Channel model | NTN TDL-C Rural |
| Antenna configuration at Satellite | 1 Rx |
| Antenna configuration at UE | 1 Tx |
| Transmission mode | SISO |
| Transmission rank | 1 |
| TBS | 256 |
| Modulation order | 16-QAM for 1 Repetition/ QPSK for other # of Repetitions |
| Number of repetitions | [1,2,4,8,16,32] |
| Channel estimation | MMSE |
| Channel coding scheme | Turbo code |
| Doppler spread | 5 Hz |
| UL DMRS config | 2 DMRS every 1 ms |

The connection density results are shown in Table 6.

Table A6

Performance metrics and results for NTN eMTC

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| Parameter | Values | | | |
| For FRF = 1 | | For FRF = 3 | |
| Service Profile | Full buffer | | Full buffer | |
| 1 percentile pre-processing SINR | ‒5.08 dB | | 3.27 dB | |
| System Bandwidth (W) | 1.08 MHz, 180 KHz | | 1.08 MHz, 180 KHz | |
| 99th Percentile Delay | 0.0341 s | | 0.0042 s | |
| Inter-packet arrival time | 1 message/2 hours/device | 1 message/day/device | 1 message / 2 hours/device | 1 message / day/device |
| Connection Density | 2 470 Devices/ km2 ,  411 Devices/ km2 | 29,641Devices/ km2 , 4940 Devices/km2 | 9 306 Devices/ km2 ,  1 551 Devices/ km2 | 111,672 Devices/km2,  18,612 Devices/km2 |

**Company B**

For connection density evaluations, we follow the procedure and assumptions mentioned in M.2514 [1] and M.2412 [2], for full buffer scenario. We have evaluated NR NTN; the evaluation assumptions are provided in Table 1 below.

Table B1

LLS parameters for NR-NTN mMTC evaluations

|  |  |
| --- | --- |
| Physical channel | PUSCH |
| Simulation bandwidth (=bandwidth allocated per UE) | 1 PRB |
| SCS | 15 kHz |
| Link-level Channel model | NTN TDL-C Rural |
| Antenna configuration at Satellite | 1Rx |
| Antenna configuration at UE | 1Tx |
| Transmission mode | SISO |
| Transmission rank | 1 |
| TBS | Based on MCS Sweep |
| Modulation order | Based on MCS Sweep |
| Number of repetitions | 1 |
| Channel estimation | LMMSE |
| Channel coding scheme | LDPC |
| Doppler spread | 5 Hz |
| UL DMRS config | 2 DMRS per slot |

Based on different inter-packet arrival times, we report the connection density in Table 2.

Table B2

Performance metrics for NR-NTN mMTC

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| Parameter | Values | | | |
| For FRF = 1 | | For FRF = 3 | |
| Service Profile | Full buffer | | Full buffer | |
| 1 percentile pre-processing SINR | ‒3.2 dB | | 5.2 dB | |
| System Bandwidth (W) | 180 kHz | | 180 kHz | |
| 99th Percentile Delay | < 32 ms | | < 32 ms | |
| Inter-packet arrival time | 1 message/2 hours/device | 1 message/day/device | 1 message/2 hours/device | 1 message/day/device |
| Connection Density | 316 Devices/km2 | 3 792 Devices/km2 | 5 368 Devices/km2 | 64 416 Devices/km2 |

\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_

1. ATIS IEG registration: <https://www.itu.int/oth/R0A05000019/en> [↑](#footnote-ref-1)