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| **Radiocommunication Study Groups** | **A logo of a globe with lightning bolt and blue text  Description automatically generated** |
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| **English only  TECHNOLOGY ASPECTS** |
| **Wireless World Research Forum (WWRF)** | |
| Evaluation Report For The IMT-2020 Candidate RIT “EUHT-5G”  Submitted by Nufront | |

This contribution contains the final evaluation report from the Independent Evaluation Group (IEG) Wireless World Research Forum (WWRF) for the candidate IMT-2020 radio interface(s) ‘EUHT-5G’ submitted by Proponent ‘Nufront’. As stated in Document [IMT-2020/87(Rev.1)](https://www.itu.int/md/R15-IMT.2020-C-0087/en) – *Schedule for Revision 3 of Recommendation ITU-R M.2150,* new technology proposals for Recommendation[ITU-R M.2150](http://www.itu.int/rec/R-REC-M.2150/en) could be submitted to ITU-R Working Party (WP) 5D. To this end, Nufront submitted its revised RIT ‘EUHT-5G’ to WP 5D.

The evaluation, which is based on the new EUHT-5G specifications, follows the characteristics defined in ITU-R Reports M. 2410-0, M. 2411-0 and M. 2412-0 [1] – [3] using a methodology described in Report ITU-R M.2412-0 [3].

The final evaluation report follows the following structure.

• Part I: Administrative Aspects of the WWRF

• Part II: Technical Aspects of the work of WWRF

• Part III: Conclusions

# **Part I: Administrative aspects of the Independent Evaluation Group**

# **I-1 Name of the Independent Evaluation Group (IEG)**

Wireless World Research Forum (WWRF).

# **I-2 Introduction and background of the Independent Evaluation Group**

WWRF aims to promote research that will enable limitless communications to tackle key societal challenges in the future. The term "Wireless World" broadly encompasses the support of innovation and business, social inclusion, and infrastructural challenges. This will be accomplished by developing a variety of new technological capabilities, ranging from wide-area networks to short-range communications, machine-to-machine communications, sensor networks, wireless broadband access technologies, and optical networking, along with enhanced intelligence and virtualisation in networks. This will support a reliable future Internet of people, knowledge, and things, and the creation of a service universe. WWRF serves as the unique forum where the wireless community can address key research challenges. By identifying issues, bringing them to the attention of opinion leaders, and collaborating with liaison partners to address them, WWRF drives the development of the Wireless World. WWRF hosts two major events each year, combining contributions from industry and academic experts, the exchange of ideas, and the evolution of the research agenda and technology roadmaps. WWRF has a robust publication programme, working with partners such as IEEE and Wiley, to disseminate key messages and results to the wireless research sector. To facilitate standardisation, WWRF harmonises and shares views, and, together with major liaison partners, initiates collaborative research and develops the global vision.

Over the past decade, WWRF has led several initiatives focused on the wireless evolution to and beyond 5G, including workshops, special sessions, presentations, white papers, and journal special issues. WWRF has actively supported the ITU’s evaluation process for IMT-2020 and participates as an independent evaluation group (IEG).

For the last five years, beginning in 2019, the IEG has been fully engaged in the WP5D IMT-2020 process for evaluation of IMT-2020 candidate technologies. The group has participated in the evaluation of 4 candidate radio interface technologies (RITs) as of today. These activities were performed:

* Initially in the context of Step 4 which was open for all submitted RITs,
* Next in the re-engagement of the evaluation (Option 2) for two specific RITs that did not receive a complete evaluation,
* In IMT-2020 submission and evaluation process for M.2150 “Revision after Year 2021”, completed in 2022.
* More recently in Revision 3 of Recommendation ITU R M.2150, planned to complete in 2025.

The evaluated technologies are listed below:

* TSDSI (IMT-2020/19)
* NUFRONT (IMT-2020/18 and IMT-2020/18(Rev1))
* ETSI (TC DECT) and DECT Forum (IMT-2020/17 and IMT-2020/17(Rev1))
* EUHT-5G (IMT-2020/75 for M.2150 “Revision after Year 2021”)
* EUHT-5G (IMT-2020/88 for M.2150 Revision 3)

The contributed material to the respective WP 5D meetings is summarized in the following Table:

|  |  |  |
| --- | --- | --- |
| Meeting | Document | Remarks |
| WP5D #34  (02-2020) | 5D/120-E | Final evaluation report for RIT submissions From TSDSI (IMT-2020/19) and NUFRONT (IMT-2020/18) |
| WP5D #37  (02-2021) | 5D/476 | Interim evaluation report on the Candidate Technology Submission for FOR IMT-2020 “ETSI (TC DECT) and DECT Forum Proponent” As Part of the Re-engagement in Step 4 Evaluation (Report with Provisional Results). |
| WP5D #37  (02-2021) | 5D/475 | Interim evaluation report on the Candidate Technology Submission for IMT-2020 “EUHT” as part of the re-engagement in Step 4 Evaluation. |
| WP5D #38  (06-2021) | 5D/658 | Evaluation report on the Candidate Technology Submission for IMT-2020 “ETSI (TC DECT) and DECT Forum Proponent” as part of the re-engagement in Step 4 evaluation. |
| WP5D #38  (06-2021) | 5D/659 | Evaluation report on the Candidate Technology Submission for IMT-2020 “EUHT” as part of the re-engagement in Step 4 Evaluation |
| WG Technology Aspects Interim Meeting  (08-2021) | 5D/736 | Updated final evaluation report on the Candidate Technology Submission for IMT-2020 “ETSI (TC DECT) and DECT Forum Proponent” as part of the re-engagement in step 4 evaluation. |
| WG Technology Aspects Interim Meeting  (08-2021) | 5D/743 | Interim report based on further evaluations on the Candidate Technology Submission for IMT-2020 “EUHT technology” as part of the re-engagement in step 4 evaluation. (Final results were included subject to minor clarification from the Nufront proponent) |
| WP5D #39  (10-2021) | 5D/760 | Final report including re-evaluation of the final results for the Candidate Technology Submission for IMT-2020 “EUHT technology” as part of the re-engagement in step 4 evaluation. |
| WP5D #41  (06-2022) | 5D/882 | Interim Evaluation Report for the candidate IMT-2020 RIT "EUHT 5G" submitted by Nufront for M.2150 "Revision after year 2021" |
| WP5D#42  (10-2022) | 5D/1061 | Final evaluation report for the candidate IMT-2020 RIT "EUHT 5G" submitted by Nufront for M.2150 “revision after year 2021” |

**I-3 Method of work**

The evaluation method in this report is in line with what are suggested in Report ITU-R M.2412 [3] that are inspection, analysis and simulation.

## I-3-1 Organizational Issues

The work was organized using the following channels:

1. Regular online meetings of the steering board (SB) of WWRF
2. WWRF’s Workshop with ARIB IEG (September 2024)
3. Weekly meetings of the technical teams
4. File sharing through secure shared space
5. Monitoring of the ITU Discussion Forum created for the IEGs and the Proponent

## I-4 Administrative contact details

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# **Part II: Technical aspects of the work of the Independent Evaluation Group**

# **II-A What candidate technologies or portions of the candidate technologies this IEG is or might anticipate evaluating?**

The WWRF IEG has evaluated a portion of the candidate RIT, based on the following submitted material:

|  |  |  |
| --- | --- | --- |
| Meeting number | Input contributions | Remarks |
| WP 5D #45 | 5D/[51](https://www.itu.int/dms_ties/itu-r/md/23/wp5d/c/R23-WP5D-C-0051!!MSW-E.docx)  (Attachment Part 1: 5D/[51!P1](https://www.itu.int/dms_ties/itu-r/md/23/wp5d/c/R23-WP5D-C-0051!P1!ZIP-E.zip);  Attachment Part 2: 5D/[51!P2](https://www.itu.int/dms_ties/itu-r/md/23/wp5d/c/R23-WP5D-C-0051!P2!ZIP-E.zip);  Attachment Part 3: 5D/[51!P3](https://www.itu.int/dms_ties/itu-r/md/23/wp5d/c/R23-WP5D-C-0051!P3!ZIP-E.zip);  Attachment Part 4: 5D/[51!P4](https://www.itu.int/dms_ties/itu-r/md/23/wp5d/c/R23-WP5D-C-0051!P4!ZIP-E.zip);  Attachment Part 5: 5D/[51!P5](https://www.itu.int/dms_ties/itu-r/md/23/wp5d/c/R23-WP5D-C-0051!P5!ZIP-E.zip));  Attachment Part 6: 5D/[51!P6](https://www.itu.int/dms_ties/itu-r/md/23/wp5d/c/R23-WP5D-C-0051!P6!ZIP-E.zip)); | * Final submission * • Characteristics template * • Compliance template * • Link budget template * • Self-evaluation report * • EUHT-5G specification * • EUHT-5G specification change records |

The technical performance requirements listed in the table below have been assessed (Ref: Report ITU-R M.2412-0). In this Table we list for each addressed characteristic the assessment method used (based on ITU evaluation methodology), references to the requirements and exact methodology steps from corresponding ITU documents M.2410-0 and M.2412-0.

|  |  |  |  |
| --- | --- | --- | --- |
| Characteristic for evaluation (test-environment) | High-level assessment method | Reference to M.2410-0 Requirements Document | Reference to M.2412-0 Evaluation Document |
| 5th Percentile Spectral Efficiency | Simulation | § 4.4 | § 7.1.2 |
| Average Spectral Efficiency | Simulation | § 4.5 | § 7.1.1 |
| Connection density (mMTC) | Simulation | § 4.8 | § 7.1.3 |

# **II-B Confirmation of utilization of the ITU-R evaluation guidelines in Report ITU-R M.2412**

The IEG is cognisant of the ITU-R evaluation guidelines and the evaluation plan is developed under the light of those guidelines.

# **II-C Documentation of simulation-based evaluation methodology**

## II-C-1 Average & 5th Percentile Spectral Efficiency

## 5th Percentile Spectral Efficiency:

According to Report ITU-R M.2410 [1], the 5th percentile user spectral efficiency represents the value at the 5% point of the cumulative distribution function (CDF) of normalised user throughput. This normalised user throughput is calculated as the number of correctly received bits (i.e., the bits in the Service Data Units (SDUs) delivered to Layer 3) over a specific period, divided by the channel bandwidth, and is expressed in bit/s/Hz.

ITU-R M.2412 [3] mandates that the 5th percentile user spectral efficiency be evaluated alongside the average spectral efficiency using the **same** **simulation**. Consequently, the evaluation results for the 5th percentile user spectral efficiency are presented together with the average spectral efficiency in Section II-D-1 and II-D-2 of this report.

**Average Spectral Efficiency:**

As outlined in Report ITU-R M.2410 [1], average spectral efficiency is calculated by taking the total throughput of all users (the number of correctly received bits, i.e., the bits in the Service Data Units (SDUs) delivered to Layer 3, over a given period) and dividing it by the channel bandwidth of a specific band, then further dividing by the number of TRxPs. This metric is expressed in bit/s/Hz/TRxP.

Report ITU-R M.2412 [3] stipulates that average spectral efficiency and 5th percentile user spectral efficiency must be evaluated together using the same simulation. For EUHT-5G, both average spectral efficiency and 5th percentile user spectral efficiency are assessed, considering a variety of antenna configurations and transmission schemes.

### II-C-1-A Summary of the new EUHT-5G specification

To the best of our knowledge and after a thorough comparison of the previous submission of EUHT-5G (Doc. [5D/979](https://www.itu.int/md/R19-WP5D-C-0979/en)), following are the major changes found in the new EUHT-5G specification ([ITU-WP5D SharePoint](https://www.itu.int/md/R23-WP5D-C-0051/en)). We have highlighted potential benefits of these changes and their associated KPIs.

* **Antenna Ports at the Base Station**

The use of up to 32 antenna ports at the base station can significantly enhance EUHT-5G performance by enabling advanced MIMO techniques. This may increase the capacity and coverage of the network, providing **higher data rates** and **improved reliability**.

* **Higher Modulation Schemes**

Implementing up to 4096-QAM can allow EUHT-5G networks to transmit **more bits per symbol (may improve spectral efficiency)**, hence positively impacting the spectral efficiency. This higher modulation order increases the data throughput, making more efficient use of the available spectrum.*However, it requires a higher SNR to maintain signal quality, making it most effective only in areas with excellent signal conditions.*

* **Supporting more sub-Channels in a single component carrier**

Based on the new EUHT-5G specification, the network can support up to 10 sub-channels within a single component carrier. This granularity may allow for more flexible and **efficient spectrum use (may enhance spectral efficiency)**, enabling the network to serve multiple users with **varying bandwidth requirements** simultaneously and adaptively improving the **network capacity**.

* **Flexible Carrier Aggregation (CA)**

Carrier aggregation in the revised EUHT-5G is more flexible, allowing the combination of multiple frequency bands to increase the total available bandwidth. This flexibility may allow using non-contiguous spectrum efficiently and provide **higher peak data rates**.

* **Detailed Description of Handovers**

The EUHT-5G revision provides more detailed procedures for network joining and handover for seamless connectivity and **minimal interruption** when users move between different cells.

* **More Flexible Phase Tracking Pilots**

Flexible phase tracking pilots in the new EUHT-5G specification can help maintain accurate synchronisation of the signal phase between the transmitter and receiver, even in challenging environments. This may support **high mobility** with greater signal quality and also may improve **reliability**.

* **More Reliable Preambles in Low Error Mode**

EUHT-5G revision employs more reliable preambles, especially in low error mode, which improves the accuracy of initial access and synchronisation processes. This may enhance **reliability**.

* **More MCSs in Low Error Mode**

The introduction of more Modulation and Coding Schemes (MCSs) in low error mode may allow EUHT-5G to adapt more precisely to varying signal conditions. This flexibility optimises the trade-off between data rate and error resilience, providing a more stable and **reliable** connection, particularly in environments with fluctuating signal quality (such as the cell-edge).

* **Overall, more MCSs**

EUHT-5G revision introduces a wider range of MCSs for control channels and signalling/feedback channels. This enhancement improves the network **efficiency and reliability**.

### II-C-1-B Design for the simulator

### Link level Simulator Design:

The link-level and system-level simulators work together to provide a comprehensive evaluation of network performance. The link-level simulator focuses on the physical layer, simulating the transmission and reception of data packets under various channel conditions to determine the spectral efficiency for individual links. This involves detailed modelling of modulation, coding, channel estimation, and decoding processes. The system-level simulator, on the other hand, considers the entire network layout, including the distribution of users, resource allocation, and interference management. It aggregates the results from multiple link-level simulations to evaluate overall network performance metrics such as average spectral efficiency and 5th percentile user spectral efficiency. By combining the detailed physical layer insights from the link-level simulator with the broader network-level analysis from the system-level simulator, a holistic understanding of the network's capabilities and performance is achieved. This integrated approach ensures that both individual link performance and overall network efficiency are accurately assessed as per the guidelines in [3].

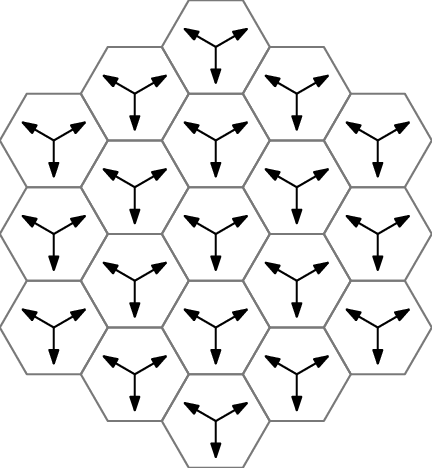


Figure 1. 19-Cell scenario with 3 sites per cell (57 sites)

### System level Simulator Design:

### II-C-1-C Channel Modelling

The configuration parameters have been sourced from Annex 1 of Rep. ITU-R M.2412-0 [3]. Since some parameters are specified as ranges, we have modelled evaluations using multiple values within these ranges to ensure the technical performance requirements are accurately assessed, rather than relying solely on the extreme values.

The simulation model for evaluating spectral efficiency at a 4GHz carrier frequency considers the 'full buffer best effort' service profile. The simulation bandwidth can be up to 100 MHz (details included in next sub-sections). For EUHT-5G, a subcarrier spacing of 78.125 kHz is used as per the recommendation in self-evaluation report. The evaluation distinguishes between non-line-of-sight (NLoS) and line-of-sight (LoS) conditions, as the tapped delay line (TDL) models differ for each. Following Nufront's self-evaluation, the NLoS scenario is considered. The TDL fading distribution is Rayleigh, with tap delays and normalised power specified in TABLE A1-41. Delay and angular spreads are taken from Table A4-9 (UMa) in Annex 1. Path loss and shadow fading models are provided in TABLE A1-3 for both LoS and NLoS. The channel coefficient generation procedure follows figure A1-2, starting with general parameters and progressing to small-scale parameters, resulting in channel coefficient generation.

### II-C-1-D Simulation parameters and technical assumptions for Indoor eMBB

Following are the simulation parameters used in the link and system level simulations for evaluating average and 5th percentile spectral efficiency Indoor hotspot scenario.

***Table 1. Simulation Parameters and Assumptions (Link and System Level) for Indoor Hotspot***

|  |  |
| --- | --- |
| Indoor Hotspot - eMBB | Configuration A |
| Carrier frequency for evaluation | 4 GHz |
| BS antenna height | 3 m |
| Transmit power per TRxP | 21 dBm for 10MHz bandwidth |
| Inter-site distance | 20m |
| BS noise figure | 5 dB |
| UE noise figure | 7 dB |
| Device deployment | 100% indoor |
| UE speeds of interest | 3 km/h (Indoor) |
| Traffic model | Full buffer |
| Simulation bandwidth | 10MHz |
| UE density | 10 UEs per TRxP |
| UE antenna height | 1.5m |
| Channel model variant | Channel model A |
| Handover margin (dB) | 0 |
| Antenna Configuration and Parameters | |
| Number of antenna elements per TRxP | 32Tx/Rx |
| Number of TXRU per TRxP | 32TXRU |
| Number of UE antenna elements | 4Tx/Rx |
| Number of TXRU per UE | 4TXRU |
| BS antenna element gain | 5dBi |
| UE antenna element gain | 0 dBi |
| UE antenna element pattern | Omni-directional |
| Mechanic tilt | 180° in GCS |
| Electronic tilt | 90° in LCS |
| TRxP number per site | 1 |

***Table 2. Simulation Parameters for the PHY layer – Indoor Hotspot***

|  |  |
| --- | --- |
| Parameters | Values |
| Modulation | Up to 4096 QAM |
| Channel Coding | LDPC |
| Multiple access | OFDMA |
| Duplexing | TDD |
| Subcarrier Spacing | 78.125 KHz |
| Simulation bandwidth | 20 MHz |
| Transmission Scheme | DL: SU/MU-MIMO, UL: SU-MIMO |
| Frame structure | DL:UL = 2:1 |
| Antenna configuration at TRxP | 32Tx, (16,4,2,1,1;4,4) |
| Antenna configuration at UE | 8Rx, (1,4,2,1,1;1,4) |
| Scheduling | Proportional Fairness (PF) |
| Receiver | MMSE-IRC |
| Channel estimation | Non-ideal (as per Nufront’s SER) |

### II-C-1-E Simulation parameters and technical assumptions for Dense Urban Macro

Following are the simulation parameters used in the link and system level simulations for evaluating average and 5th percentile spectral efficiency Dense Urban Macro scenario.

***Table 3. Simulation Parameters and Assumptions (Link and System Level) for Urban Macro***

|  |  |
| --- | --- |
| Urban Macro - eMBB | Configuration A |
| Carrier frequency for evaluation | 4 GHz |
| BS antenna height | 25 m |
| Total transmit power per TRxP | 41 dBm for 10MHz bandwidth |
| Inter-site distance | 200m |
| BS noise figure | 5 dB |
| UE noise figure | 7 dB |
| Device deployment | 80% indoor and 20% Outdoor |
| UE speeds of interest | 3 km/h (Indoor) and 30 km/h Outdoor |
| Traffic model | Full buffer |
| Simulation bandwidth | 10MHz |
| UE density | 10 UEs per TRxP |
| UE antenna height | 1.5m Outdoor Users |
| Channel model variant | Channel model A |
| Handover margin (dB) | 0 |
| Antenna Configuration and Parameters | |
| Number of antenna elements per TRxP | 128 Tx/Rx |
| Number of TXRU per TRxP | 4 TXRU |
| Number of UE antenna elements | 4 Tx/Rx |
| Number of TXRU per UE | 4 TXRU |
| BS antenna element gain | 8 dBi |
| UE antenna element gain | 0 dBi |
| UE antenna element pattern | Omni-directional |
| Mechanic tilt | 90° in GCS |
| TRxP number per site | 3 |

***Table 4. Simulation Parameters for the PHY layer –Dense Urban***

|  |  |
| --- | --- |
| Parameters | Values |
| Modulation | Up to 4096 QAM |
| Channel Coding | LDPC |
| Multiple access | OFDMA |
| Duplexing | TDD |
| Subcarrier Spacing | 78.125 KHz |
| Simulation bandwidth | 20 MHz |
| Transmission Scheme | DL: SU/MU-MIMO, UL: SU-MIMO |
| Frame structure | DL:UL = 2:1 |
| Antenna configuration at TRxP | 32Tx, (16,4,2,1,1;4,4) |
| Antenna configuration at UE | 8Rx, (1,4,2,1,1;1,4) |
| Scheduling | Proportional Fairness (PF) |
| Receiver | MMSE-IRC |
| Channel estimation | Non-ideal (as per Nufront’s SER) |

## II-C-2 Connection Density (Urban Macro mMTC)

### II-C-2-A ITU Requirement & Evaluation methodology

#### II-C-2-A-1 Minimum requirement

Connection density represents the total number of devices fulfilling a specific quality of service (QoS) per unit area (per km2) as defined in ITU-R M.2410-0. The target QoS is to support delivery of a message of a certain size within a certain time and with a certain probability of success, as specified in ITU-R M.2412-0. This requirement is defined for the purpose of evaluation in the mMTC usage scenario. The minimum requirement for connection density is 1 000 000 devices per km2, which should be achieved with a maximum delay of 10s and success probability of at least 99%.

#### II-C-2-A-2 Evaluation Methodology

Connection density is evaluated through simulation. The system simulation methodology for the connection density KPI evaluation is detailed in M.2412. The methodology details two options:

• Non-full buffer system-level simulation.

• Full-buffer system-level simulation followed by link-level simulation.

In our evaluation study, we have applied the full buffer approach. The generic steps described in M.2412 are the following:

*Step 1:* Perform full-buffer system-level simulation using the evaluation parameters for Urban Macro-mMTC test environment, determine the uplink *SINR*i for each percentile *i*=1…99 of the distribution over users, and record the average allocated user bandwidth *W*user.

– In case UE multiplexing on the same time/frequency resource is modelled in this step, record the average number of multiplexed users *Nmux*. *Nmux* = 1 for no UE multiplexing.

*Step 2:* Perform link-level simulation and determine the achievable user data rate *Ri* for the recoded *SINRi* and *W*uservalues.

– In case UE multiplexing on the same time/frequency resource is modelled in this step, record the average number of multiplexed users *nmux,i* under *SINRi* . The achievable data rate for this case is derived by *Ri = Zi/nmux,i*, where aggregated bit rate *Zi* is the summed bit rate of *nmux,i* users on *W*user. *nmux,i* = 1 for no UE multiplexing.

*Step 3:* Calculate the packet transmission delay of a user as *D*i = *S*/*R*i, where *S* is the packet size.

*Step 4:* Calculate the traffic generated per user as *T* = *S*/*T*inter-arrival, where *T*inter-arrival is the inter‑packet arrival time.

*Step 5:* Calculate the long-term frequency resource requested under *SINRi* as *B*i = *T*/(*R*i/*W*user).

*Step 6:* Calculate the number of supported connections per TRxP, *N* = *W* / mean(*B*i). *W* is the simulation bandwidth. The mean of *B*i may be taken over the best 99% of the *SINRi* conditions.

– In case UE multiplexing is modelled in *Step 1*, *N* = *N*mux × *W* / mean(*B*i). In case UE multiplexing is modelled in *Step 2*, *N* = *W* / mean(*B*i/*nmux,i*).

*Step 7:* Calculate the connection density as *C* = *N* / *A*, where the TRxP area *A* is calculated as *A* = ISD2 × sqrt(3)/6, and ISD is the inter-site distance.

The requirement is fulfilled if the 99th percentile of the delay per user Di for a packet size of 32 bytes is less than or equal to 10s, and the connection density is greater than or equal to 1 000 000 devices.

#### II-C-2-A-3 Test Environments and Configurations

Connection Density is relevant for the massive machine type communications (mMTC) usage scenario (M.2412 - §8.1). This usage scenario is characterized by a very large number of connected devices typically transmitting a relatively low volume of non-delay-sensitive data.

Connection Density should be assessed in an urban macro (Urban Macro–mMTC) testing environment (M.2412 - §8.2) targeting continuous coverage focusing on a high number of connected machine type devices.

Finally, Connection Density may be evaluated under 2 possible configurations (M.2412 - §8.4), Configuration A and B either on Uplink or Downlink. In our evaluation study, the uplink direction for configuration A has been assessed.

The parameters are detailed in the following Table.

Table 5: Connection Density evaluation parameters

|  |  |
| --- | --- |
| **Parameters** | **Urban Macro–mMTC** |
| **Connection Density Evaluation** |
| **Configuration A** |
| **Baseline evaluation configuration parameters** | |
| Carrier frequency for evaluation | 700 MHz |
| BS antenna height | 25 m |
| Total transmit power per TRxP | 46 dBm for the Operational Bandwidth (10 MHz). |
| UE power class | 23 dBm |
| Percentage of high loss and low loss building type | 20% high loss, 80% low loss |
| **Additional parameters for system-level simulation** | |
| Inter-site distance | 500 m |
| Number of antenna elements per TRxP | 8 antennas with the element patterns provided in M.2412 (MRC for reception, beamforming for unicast transmissions) |
| Number of UE antenna elements | 2 isotropic |
| Device deployment | 80% indoor, 20% outdoor  Randomly and uniformly distributed over the area |
| UE mobility model | Fixed and identical speed |v| of all UEs of the same mobility class, randomly and uniformly distributed direction. |
| UE speeds of interest | 3 km/h for indoor and outdoor |
| Inter-site interference modelling | Explicitly modelled |
| BS noise figure | 5 dB |
| UE noise figure | 7 dB |
| BS antenna element gain | 8 dBi |
| UE antenna element gain | 0 dBi |
| Thermal noise level | ‒174 dBm/Hz |
| Traffic model | With layer 2 PDU (Protocol Data Unit) message size of 32 bytes:  1 message/day/device  or  1 message/2 hours/device  Packet arrival follows Poisson arrival process for non-full buffer system-level simulation. The target was set to 1 message /2 hours / device according to the suggestion. |
| Simulation bandwidth | 10 MHz (either as one channel) |
| UE density | Ten UEs per TRxP |
| UE antenna height | 1.5 m |

### II-C-2-B IEG Evaluation Methodology Detailing

An end-to-end event-based system and link level layer simulator for the EUHT-5G technology was developed in MATLAB by WWRF IEG, able to perform the required simulation-based evaluation campaign. The IEG developed a simulator that is able to take into account the particularities of the EUH-5G RIT, including the latest submission features, while remaining aligned with the evaluation guidelines defined in ITU-R M.2412-0. Channel modeling implementation follows M.2412 assumptions as well.

#### II-C-2-B-1 Implementation

The connection density evaluation methodology is implemented in the following steps:

*Step 1*: Frequency planning options are investigated based on the available number of channels and the simulation bandwidth. Given that the smallest supported bandwidth for EUHT-5G is 5MHz and the simulation bandwidth in Configuration A is 10 MHz, there was no possibility to implement frequency reuse of 1/3 and 1/7. A single 10 MHz carrier for all TRxPs and reuse 1 are assumed.

OFDM subcarrier spacing is set to 19.53125 kHz (low frequency, low Doppler) and the size of FFT is 512. The demodulation reference signals are placed every four subcarriers and every four OFDM symbols. The twelve phase tracking pilots are repeated at every OFDM subcarriers.

*Step 2*: The packet to be sent is 32 bytes, i.e., 256 bits. Adding the PDU headers according to the proposal, the Cyclic Redundancy Check (CRC) suffix and applying a ½ convolutional encoder in order to enhance reliable transmission, the total number of bits to be send is approximately 740 bits. According to the selected PHY and pilot pattern configuration, for either BPSK or QPSK modulation, two OFDM symbols per packet repetition per user should be utilized.

It is assumed that there is no traffic pattern generation process, since all 32 bytes are available to the STA at the beginning of the simulation.

*Step 3*: No multiplexing is performed at the uplink. Each time, all the resources are allocated to a single user (the target user for the evaluation process).

*Step 4*: PDU repetition is performed to enhance reliability. The effectiveness of repetitions in the reliability is evaluated. It is noted that repetitions up to four times are considered for the normal mode of operation and up to twelve times for the low-error mode of operation.

*Step 5*: The SINR Cumulative Density Function (CDF) distribution is extracted assuming that there is constant demand by users at all cells. Since, for the Connection Density evaluations, high congestion of users is expected, the CDF can be used to statistically generate the SINR for each user, when performing mMTC system-level simulations.

It is assumed that all neighbouring cells have allocated resources to other STAs and therefore, system-wise there are 57 interferers at a given time.

*Step 6*: In the analysis, the EUHT-5G frame duration was (approximately) 4 msec following the sampling period/time granularity of the simulator. This means that the time taken from the request of resources to the acknowledgement of reception at the downlink will be at least 16 msec (without taking into account the initial delays for synchronization and random access).

*Step 7*: TDD duplex mode is considered. The DL/UL ratio in the EUHT-5G frame dynamically changes to optimize performance. The minimum necessary slots are allocated for downlink, that carry the reference signals (e.g., DL-preamble, DL-DRS, CCH, DL-TCH), as well as the required scheduling information, and acknowledgments. It is noted that according to the described operation, a large portion is assigned to DL for each frame to carry the CCH symbols for scheduling and all responses and acknowledgments. A typical ratio for DL/UL is ½.

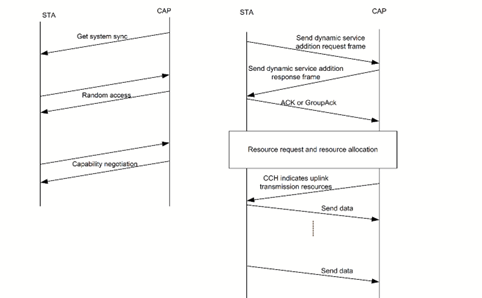
*Step 8*: Link Level simulation is performed for the specified PHY configuration using the proposed channel model. Packet error rate curves are derived.

*Step 9*: The following transmission assumptions are applied:

* TRxPs with 8 antennas.
* Transmission in the uplink is based on QPSK and ½ LDPC (MCS1) or BPSK and ½ LDPC (MCS0) depending on the quality of the channel (as perceived by the reception of DL signals).
* Transmission in the downlink is based on:
  + BPSK and Convolutional Coding or QPSK and LDPC 3/14 for SICHs (Type I, II)
  + QPSK with LDPC 4/7 or QPSK with LDPC 3/14 for CCHs (Type I, II)
  + MCS1 or MCS0 for other signals/channels/responses contained in DL-TCH or UL-TCH.
* Sounding symbols were not used.
* Variable number of repetitions and maximum number of retransmissions (ARQ process).

*Step 10*: At this point, the main loop of the simulation engine can be executed.

* Ten UEs are generated per TRxP and one UE is selected for transmission at the next opportunity. The three UEs located at the central cells are assessed in terms of rate, reliability and latency. The UEs at the other cells are considered interference sources. The SINR value corresponds to the results of Step 5.
* In case of an unsuccessful transmission, then an ARQ-like process is activated (according to the EUHT-5G re-transmission strategy). The retransmission is initiated instantly, and the whole process will be prioritized at the next frame.
* Channels are generated using the IMT-2020 channel models. The channels are produced for a significantly long period to cover the possibility for a maximum number of retransmissions.
* For each retransmission, we isolate the time samples from the generated channels corresponding to the time-variant impulse responses. As far as the large-scale characteristics are concerned, for each retransmission the pathlosses are considered equal, but on the other hand, a new shadowing coefficient is generated for each retransmission.
* The packet is received correctly, if:
  + All packets exchanged to realize the process are successfully decoded (CRC check).
  + PDU repetitions utilize soft decoding, however, the demodulation and decoding attempt for each retransmission is performed independently.
* If the maximum number of retransmissions is reached, a transmission failure is marked.
* The process is repeated multiple times to estimate the achievable rate (according to the evaluation methodology in II-C-2-A-2) that relies on the average number of re-transmissions and the packet outage, i.e., the packets that are not successfully sent despite coding, repetitions, and retransmissions.
* More than 50,000 channel instances were used for the evaluation.



**Figure 2: UL Transmission Process a) Initial steps for network joining, b) Steps for allocation of service, resources and data transmission**

#### II-C-2-B-2 PHY Configuration

In the following Table, a summary of the physical layer parameters considered in the evaluation is provided.

Table 6: Physical Layer Parameters

|  |  |
| --- | --- |
| **Parameter** | **Value** |
| Channel Bandwidth | 10 MHz |
| Nfft | 512 @ 10 MHz were tested. |
| Subcarrier Spacing | 19.53125 kHz for the considered Nfft/BW setup |
| Cyclic Prefix | N/4 (normal) |
| Frame Structure | As provided by the Proponent in Figure 69 of EUHT specifications    It is noted that no sounding channels were considered. |
| Frame duration | Approximately 4 ms (62 OFDM symbols in 10MHz/512subcarriers configuration). |
| TDD Ratio | DL/UL ratio is set to ½. The UL-TCH OFDM symbols are 20. |
| Modulation and Coding | BPSK or QPSK.  Convolutional Coding 1/3, LDPC 3/14, LDPC 1/2, LDPC 4/7 depending on the signal type and channel. |
| Receiver | MMSE-IRC for the first-tier neighboring stations. |
| MIMO | Single User MIMO  With space-time coding at UL transmissions. |
| Repetitions | A variable number of PDU repetitions was assessed (from 1 up to 12).  Soft decoding was performed utilizing the soft bits from all the repetitions. |

#### II-C-2-B-3 MAC sublayer and Transmission process

For each 32 byte packet transmission, a quite significant number of steps should be completed according to the MAC specification of the EUHT-5G proposal. The process is presented in the EUHT-5G proposal (Figures 37 to 42 – summarized in Figure 1 of this evaluation). The detailed process was implemented as a 21-step procedure for the simulator. More specifically, the steps towards a successful transmission are the following:

1 UE Synchronization with the use of preambles.

2 Acquisition of SICH, CCH (broadcast), and the BCF carried in DL-TCH. Channel estimation is performed using the preambles. The BCF can be dynamically set. For our simulation, BCF is present in every frame (i.e., period 4ms).

3 The UE attempts to transmit a PN sequence at the UL-Random Access Channel (UL-RACH) in order to indicate its presence and eventually request services.

4 The TRxP (CAP), attempts to detect the random-access sequence. If multiple users select the same sequence, this will lead to a collision.

5 The users that experienced a collision will trigger a backoff procedure. For our simulation, no backoff at all was considered as a best-case scenario.

6 Assuming no collision, the TRxP will send a response acknowledging the reception (as a CCH) and will allocate resources to the UE for Random Access Request (RA-REQ).

7 The UE attempts to receive and decode the CCH and if it succeeds it will transmit the RA-REQ packet.

8 Upon RA-REQ reception, the TRxP will send a Random-Access Request Response (RA-RES) back to the UE.

9 Through the CCH, the TRxP will allocate resources requesting the UE basic capability set (process known as capability negotiation).

10 The UE will send the capability set.

11 The TRxP will respond on the capability negotiation

12 The UE will send an acknowledgment.

13 At the next phase, the UE will request for a service with the transmission of a dynamic service addition request frame.

14 The TRxP will attempt to receive the request and respond.

15 The UE will acknowledge.

16 The resource allocation request process also includes a random-access procedure. The UE sends a scheduling request sequence (randomly selected) in the UL scheduling request channel.

17 In case of correct reception, the TRxP will allocate resources in order to receive the scheduling request, otherwise, backoff should again be triggered.

18 The UE sends the scheduling request.

19 The resource allocation is performed.

20 The resources for the 32 bytes are now available to the UE, that will attempt transmission. No fragmentation is performed.

21 The TRxP will acknowledge correct reception. Otherwise, retransmission will be performed.

In the evaluation, only the last parts of the process is simulated (Send Dynamic Service Addition Request Frame – until the establishment of UL traffic transmission and the reception of the acknowledgement). The process is used for the evaluation of the packet outages and the calculation of the Rate for the transmission of the 32 bytes by taking into account the total required delay (that in this case exceeded 20 msec at best).

#### II-C-2-B-4 Error handling and failures

The process contains information exchange that is handled by the simulator (and based on the suggestions included in the proponent document) as follows:

* Synchronization is considered perfect and failure to decode SICH, CCH, or BCH at the initial stage is not considered.
* Failure during the random-access attempts is not considered.
* After a maximum number of consecutive failed transmissions by the UE (of any type), the transmission is dropped. Moreover, corresponding failure of transmission at the downlink (e.g., CCH for resource allocation, or acknowledgment of reception) will lead to a failure.
* After a maximum number of failed attempts to acquire resources (set to 8), the transmission is dropped.
* After a maximum number of retransmissions (set to variable sizes 4, 8), the MPDU is dropped.
* After 10s of unsuccessful transmission, the packet is dropped.

# **II-D Assessment**

### II-D-1 Average & 5th Percentile Spectral Efficiency for Indoor-Hotspot Downlink and Uplink

**Downlink:**



## Figure 3. CDF for Downlink SE from System-Level simulations (Indoor Hotspot)

Based on the CDF curve above, the evaluation results of DL spectral efficiency for EUHT-5G for evaluation configuration A are provided in Table 7. It is observed that EUHT-5G does not fulfill the DL spectral efficiency requirement for eMBB in Indoor Hotspot test environment.

***Table 7. Results for DL Indoor Hotspot, Configuration A***

| **Minimum technical performance requirements (ITU-R M.2410)** | **Category** | | | **Required value** | **Value** | **Meets the Requirement?** | **Remarks** |
| --- | --- | --- | --- | --- | --- | --- | --- |
| **Usage scenario** | **Test environment** | **Downlink or Uplink** |
| **Average Spectral Efficiency (bits/s/Hz/TRxP)** | eMBB | Indoor Hotspot | Downlink | 9 | 6.31 | **No** | *Does not meet the criteria for DL for both KPIs.*  *Observations in Section II-D-3.* |
| **5th Percentile Spectral Efficiency (bits/s/Hz)** | 0.30 | 0.2 | **No** |

**Uplink:**



## Figure 4. CDF for Uplink SE from System-Level simulations (Indoor Hotspot)

Based on the CDF curve above, the evaluation results of UL spectral efficiency for EUHT-5G for evaluation configuration A are provided in Table 8. It is observed that EUHT-5G does not fulfill the UL spectral efficiency requirement for eMBB in Indoor Hotspot test environment.

***Table 8. Results for UL Indoor Hotspot, Configuration A***

| **Minimum technical performance requirements (ITU-R M.2410)** | **Category** | | | **Required value** | **Value** | **Meets the Requirement?** | **Remarks** |
| --- | --- | --- | --- | --- | --- | --- | --- |
| **Usage scenario** | **Test environment** | **Downlink or Uplink** |
| **Average Spectral Efficiency (bits/s/Hz/TRxP)** | eMBB | Indoor Hotspot | Uplink | **6.75** | **3.88** | **No** | *Does not meet the criteria for DL for both KPIs.*  *Observations in Section II-D-3.* |
| **5th Percentile Spectral Efficiency (bits/s/Hz)** | **0.21** | **0.11** | **No** |

### II-D-2 Average & 5th Percentile Spectral Efficiency for Dense Urban Downlink and Uplink

**Downlink:**

******

## Figure 5. CDF for Downlink SE from System-Level simulations (Dense Urban Macro)

Based on the CDF curve above, the evaluation results of DL spectral efficiency for EUHT-5G for evaluation configuration A (Dense Urban test environment) are provided in Table 9. It is observed that EUHT-5G does not fulfill the DL spectral efficiency requirement for eMBB in dense urban test environment.

***Table 9. Results for DL eMBB Dense Urban Macro, Configuration A***

| **Minimum technical performance requirements (ITU-R M.2410)** | **Category** | | | **Required value** | **Value** | **Meets the Requirement?** | **Remarks** |
| --- | --- | --- | --- | --- | --- | --- | --- |
| **Usage scenario** | **Test environment** | **Downlink or Uplink** |
| **Average Spectral Efficiency (bits/s/Hz/TRxP)** | eMBB | Dense Urban | Downlink | **7.8** | **4.644** | **No** | *Does not meet the criteria for DL for both KPIs.*  *Observations in Section II-D-3.* |
| **5th Percentile Spectral Efficiency (bits/s/Hz)** | **0.225** | **0.13** | **No** |

**Uplink:**



## Figure 6. CDF for Uplink SE from System-Level simulations (Dense Urban Macro)

Based on the CDF curve above, the evaluation results of UL spectral efficiency for EUHT-5G for evaluation configuration A are provided in Table 10. It is observed that EUHT-5G does not fulfill the UL spectral efficiency requirement for eMBB in dense urban test environment.

***Table 10. Results for UL Dense Urban Macro, Configuration A***

| **Minimum technical performance requirements (ITU-R M.2410)** | **Category** | | | **Required value** | **Value** | **Meets the Requirement?** | **Remarks** |
| --- | --- | --- | --- | --- | --- | --- | --- |
| **Usage scenario** | **Test environment** | **Downlink or Uplink** |
| **Average Spectral Efficiency (bits/s/Hz/TRxP)** | eMBB | Dense Urban | Uplink | **5.4** | **3.07** | **No** | *Does not meet the criteria for DL for both KPIs.*  *Observations in Section II-D-3.* |
| **5th Percentile Spectral Efficiency (bits/s/Hz)** | **0.15** | **0.09** | **No** |

### II-D-3 Observations from the results for Spectral Efficiency

### While simulating spectral efficiency for various MCSs and Antennae configurations, following observations were made by the IEG.

### II-D-3-A Observation 1: Low Error Mode and Spectral Efficiency

### Low Error Mode: This mode does not support Multi-User Multiple Input Multiple Output (MU-MIMO), which is a technique that allows multiple users to be served simultaneously using the same frequency resources.

### Impact on Spectral Efficiency: Without MU-MIMO, the cell can only use Frequency Division Multiplexing (FDM) to serve users, which is less efficient. This results in lower spectral efficiency.

### Reason for Switching to Low Error Mode: The cell switches to this mode when the channel conditions are poor, specifically when the Signal-to-Interference-plus-Noise Ratio (SINR) of the scheduled users is less than -11 dB (as per section 1.7.1.1 of the EUHT-5G specification).

### Modulation Constraints: Under these poor conditions, higher-order modulations like 16QAM or 64QAM CANNOT be used. These modulations are typically used when the SINR is high, allowing for more bits to be transmitted per symbol.

### II-D-3-B Observation 2: Low SINR and Channel Estimation

### Low SINR at Cell Edges: Users at the edge of the cell experience low SINR, which affects the accuracy of channel estimation.

### Degraded Data Channel Performance: Poor channel estimation leads to errors in the data channel.

### Repetition and Spectral Efficiency: MCS 124 and MCS 125 introduce repetition in data transmission to improve reliability, but this repetition reduces spectral efficiency because the same data is transmitted multiple times, consuming more bandwidth.

### II-D-3-C Observation 3: SICH/CCH Transmission and Beamforming

* **SICH/CCH Transmission:** The System Information Channel (SICH) and Control Channel (CCH) are transmitted across the entire cell coverage area.
* **Lack of Beamforming Gain:** Unlike the data channel, these channels DO NOT benefit from beamforming, which focuses the signal in a specific direction to improve signal strength and quality.
* **Issues at Cell Edges:** For users at the cell edges, the SICH/CCH faces SIMILAR channel estimation issues as the data channel, leading to degraded performance.

### II-D-4 Connection Density Evaluation for Urban Macro mMTC

### II-D-4-1 Technical Performance

|  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- |
| **Minimum technical performance requirements (ITU-R M.2410)** | **Category** | | | **Required value** | **Value** | **Meets the Requirement?** | **Remarks** |
| **Usage scenario** | **Test environment** | **Downlink or Uplink** |
| **Connection density (devices/km2)** | mMTC | Urban Macro – mMTC | Uplink | 1 000 000 users with less than 1% outage for a) one message per day, b) one message per 2 hours | >1 000 000 users each one transmitting one message per 24 hours, with >3% outage | Yes  No | Refer to Section  II-D-4-2  for further analysis |

#### II-D-4-2 Observations

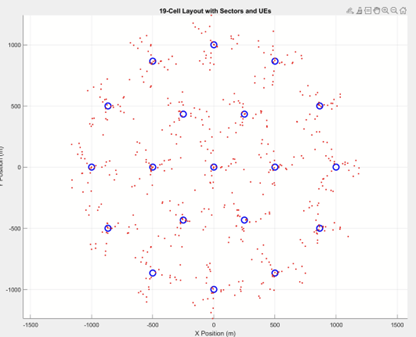
Connection density minimum technical performance level requires the simultaneous fulfilment of 3 conditions:

• At least 1 000 000 devices with a single 32-byte packet served over 24h

• Maximum delay of 10s

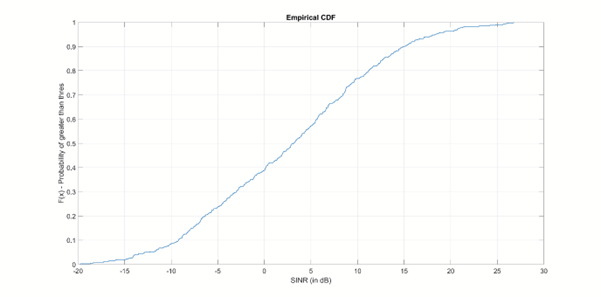
• Maximum outage probability of 1%.

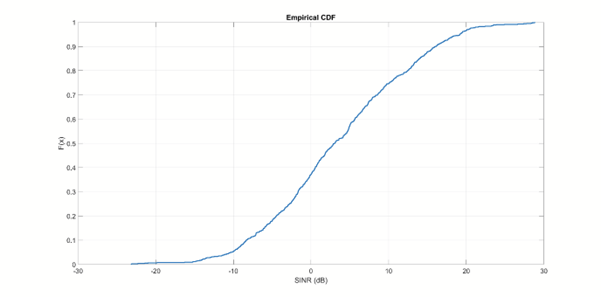
Given the number of available bandwidth resources and the quite relaxed traffic volume and delay requirements, the first two conditions may be easily met. Eventually, the minimum technical performance will depend on the achieved outage level. For 10 MHz bandwidth and assuming universal frequency reuse, a 19-cell layout with 3 sectors each leads to 57 interferers per device. At 700 MHz carrier frequency the system is heavily interference limited.



*Figure 7: An instantiation of the investigated layout. STAs from the center cell are selected as reference, while STAs from other cells are selected randomly as interferers.*

System level simulation is performed to evaluate the empirical CDFs for the SINR for both uplink and downlink, since bi-directional message exchanges are required to perform the transmission. The reference SINR is calculated at the receiver assuming perfect conditions and optimal operation. Errors (e.g., channel estimation error) will further degrade these values.

*Figure 8: Empirical CDF for the Uplink SINR – Note: calculated assuming MRC reception and perfect channel estimation.*

*Figure 9: Empirical CDF for the Downlink SINR. An uplink-limited system is considered.*

Additionally, we provide the BLER curves for the Modulation and Coding schemes used during the simulation study (Figure 5). In these figures, axis x corresponds to the narrowband (per subcarrier) Eb/No right prior to the application of the soft demodulator and decoder.

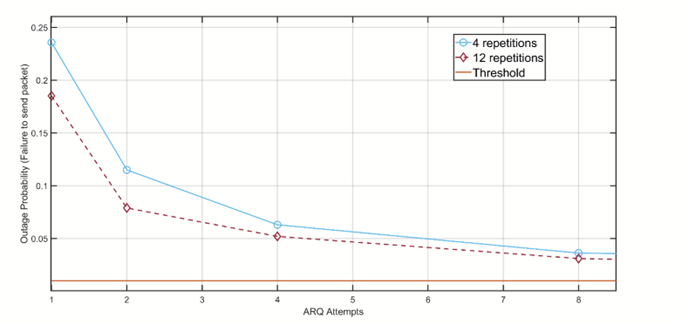
|  |  |
| --- | --- |
|  |  |
|  |  |
|  | |

*Figure 10: BLERs vs Eb/No for the Modulation and Coding schemes used in the simulator*

A baseline performance evaluation configuration is defined considering no repetition or re-transmission policy. On top of this we apply:

* Repetitions: A packet could be repeatedly transmitted several times, and soft LLR decoding combining the repeated packets is applied at the receiver. Repeated packets are quite close in time and channels are strongly time-correlated due to low doppler conditions.
* Re-transmissions: A failed packet is re-transmitted after 4 msec, a time interval corresponding to the packet duration for 512 subcarriers, which allows for shadowing decorrelation.

Initially, we fix the maximum number of repetitions to 4 -as defined in the EUHT-5G specs and the self-evaluation study- and investigate the outage for an increasing number of re-transmissions, up to 8. Table 3 provide the results derived for non-ideal channel estimation. Even at 8 re-transmissions, outage is higher than 1%. The process was repeated using 12 repetitions in order to assess the low-error mode operation (Table 4). However, the gain from the repetitions was not sufficient to fall below the outage threshold. Generally, the impact of repetitions is proven small, since the repeated segments practically share the exact same large-scale effects and channel characteristics. The impact of increasing the number of re-transmissions for the two repetition settings is showcased in Figure 6.



*Figure 11: Outage Probability vs. maximum retransmission attempts for four and twelve repetitions*

|  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| Table 11: Outage vs ARQ Attempts  (4 repetitions)   |  |  |  | | --- | --- | --- | | ARQ Attempts | Outage  (%) | Minimum Requirement Fulfilment | | 1 | 24.6 | No | | 2 | 11.5 | No | | 4 | 6.3 | No | | 8 | 3.6 | No | | Table 12: Outage vs ARQ Attempts  (12 repetitions)   |  |  |  | | --- | --- | --- | | ARQ Attempts | Outage  (%) | Minimum Requirement Fulfilment | | 1 | 18.5 | No | | 2 | 7.9 | No | | 4 | 5.2 | No | | 8 | 3.1 | No | |

# **II-F Questions and feedback to WP 5D and/or the proponents or other IEGs**

This IEG has referred to the self-evaluation report provided by Nufront and has also full considered the new technical specifications document for EUHT-5G ([ITU-WP5D SharePoint](https://www.itu.int/md/R23-WP5D-C-0051/en)).

# **II-G Proposed next steps**

The WWRF IEG will publish a final Outlook in one of its upcoming meetings in which it will include all the results in detail for all the three KPIs presented in this report.

# **Part III: Conclusions**

# **III-A Average & 5th Percentile Spectral Efficiency**

Based on the detailed observations provided, EUHT-5G does not meet the minimum criteria for both KPIs average spectral efficiency and 5th Percentile Spectral Efficiency. Only Sub 6 GHz scenarios were considered i.e., Configuration A and the candidate technology was evaluated for both DL and UL for both the KPIs. These points highlight the challenges in maintaining high spectral efficiency and reliable communication, especially for users at the cell edges and under poor channel conditions.

# **III-B** **Connection Density**

Based on the simulation-based evaluation, EUHT-5G does not meet the minimum criteria for the Connection Density KPI.

# **References & Additional Material**

1. ITU-R: Minimum requirements related to technical performance for IMT-2020 radio interface(s). Report ITU-R M.2410-0, (11/2017).
2. ITU-R: Requirements, evaluation criteria and submission templates for the development of IMT-2020. Report ITU-R M.2411-0, (11/2017).
3. ITU-R: Guidelines for evaluation of radio interface technologies for IMT-2020. Report ITU-R M.2412-0, (10/2017).