– 2nd Draft –

Methodology for the mapping of Quality of Service of 5G Mobile and 5G Fixed Wireless Access Networks

For the European Commission
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19.05.2025

Contents

1 Background

The **Digital Decade policy programme** (DDPP) guides Europe's digital transformation and represents a key means for Europe to deliver a more competitive and sustainable economy for 2030. The Commission has developed **baseline trajectories** outlining how the EU will progress according to current trends, and **projected trajectories** outlining the yearly progress to achieve the Digital Decade targets by 2030.

The **DDPP** supports investment in digital skills, the digital transformation of businesses, the digitalisation of public services and in the deployment of **secure and sustainable Gigabit and 5G infrastructure.** This is driven by the governance framework based on an **annual cooperation mechanism** involving the Commission and Member States as indicated in the Communication: 2030 Digital Compass: the European way for the Digital Decade.

The cooperation framework includes a structured, transparent and shared monitoring system based on the Digital Economy and Society Index[1] (DESI) to measure progress towards each of the 2030 targets and an annual report in which the Commission evaluates progress and provides recommendations for actions. So far, progress in the field of connectivity has been monitored on the basis of declaration of speeds collected from relevant Member States entities (NRAs and Ministries) through a very high-level methodology within the context of the DESI index including indicator "2b2 Overall 5G coverage" and indicator "2b3 5G spectrum".

However, data on the coverage of 5G fixed wireless and mobile services, gathered within the DESI framework has revealed a number of shortcomings due to the fact that the current indicators provided no information about the quality of services users have access to. This shortcoming of the 5G indicators has revealed that the need for a fully harmonised methodology capable of assessing the quality of services as actually experienced by users. This is particularly important for technologies such as 5G which promise significant improvement in the delivery of VHCN.

The Decision establishing the DDPP gives the Commission to power to adopt an implementing act to set out the key performance indicators (KPIs) to monitor the Digital Decade targets and states that those KPI should be 'updated when necessary for continued effective monitoring and to take account of technological developments'[2]. Moreover, the implementing act[3] recalls that, on the issue of 5G coverage, the Commission was to undertake further analysis to refine the measurement framework for connectivity.

In September 2023 the Commission services have proposed to the MS members of the Digital Decade Group to update the Digital Decade KPIs on connectivity and 5G in particular with **a two stages approach**.

- **The first stage** would be focused on the short term (2024-2025) by keeping the existing 5G indicator based on population coverage including all available EU-harmonised

[1] *c.f.* DESI Methodological Note - Digital Decade report 2023 | Shaping Europe's digital future (europa.eu) [1]

[2] Decision (EU) 2022/2481 establishing the Digital Decade Policy Programme, recital 24.

[3] Decision (EU) 2023/1353 setting out key performance indicators to measure the progress towards the digital targets established by Article 4(1) of Decision (EU) 2022/2481 of the European Parliament and of the Council.

frequency bands and adding a complementary indicator for high quality 5G based on the 80 MHz bandwidth concept.

- **The second stage**, which is expected to start alongside the first, will involve the development of a methodology enabling the mapping of QoS for fixed wireless and mobile broadband and 5G in particular.

The methodology presented below implements the second phase of this work which is aimed at equipping the Digital Decade monitoring framework with new 5G KPIs capable of reporting quality of 5G services at EU and at Member States level. The overall aim of this methodology is also to close any remaining gap and reach a common and fully harmonized approach valid for policy, DDPP; regulatory, EECC; and state aid contexts and the Broadband State Aid Guidelines.

This 5G QoS mapping methodology has been prepared with the assistance of an academic expert from the University of Aachen under the supervision of a steering committee made up of EC officials, academic experts, NRAs and company providing measurement tools.

The development of the document has taken into consideration a BEREC opinion (BoR (24) 188), feedback from GSMA, technical contributions from several companies with expertise in evaluating QoS of telecom services and reflected the findings of small-scale tests run by the NRAs of PL, IT, EL and HR with the assistance of the operators participating.

1.1 Scope & Objectives

This methodology for the geographical mapping of 5G mobile and fixed wireless access (FWA) broadband services builds on and complements the broadband mapping methodologies developed considering Article 22 of Directive (EU) 2018/1972 of the European Parliament and of the Council[4] in the Guidelines on Geographical Surveys of Network Deployments[5] by the Body of European Regulators for Electronic Communications (BEREC) and the "Mapping Annex" of the Guidelines on State Aid for Broadband Networks[4].

The methodology will enable the Commission to update and refine the KPIs used to measure the Digital Decade targets for connectivity coverage and improve the monitoring of Member States' progress toward these targets.

The goal of this methodology is to serve as a *common and fully harmonized* approach to 5G broadband mapping, enabling a meaningful comparison of the estimated quality of service (QoS) of 5G mobile and FWA networks across the member states (MSs) of the European Union (EU). This common EU methodology for 5G QoS mapping is also intended to be *valid for policy, regulatory, and state aid contexts*, thus preventing the undue burden of the MS's National Regulatory Authorities (NRA) or Other Competent Authorities (OCA) making

[4] Directive (EU) 2018/1972 of the European Parliament and of the Council of 11 December 2018 establishing the European Electronic Communications Code (OJ L 321, 17.12.2018, p. 36).

[5] The BEREC Guidelines to assist NRAs on the consistent application of geographical surveys of network deployments – BoR (20) 42. [4] European Commission Communication from the Commission: Guidelines on state aid for broadband networks - Annex I Mapping (OJ C 36, 31.1.2023, p. 1).

multiple requests for 5G mapping information and corresponding data towards mobile network operators (MNOs) to fulfill their broadband mapping obligations in these various contexts.

Regarding the monitoring of the Digital Decade targets established in the EU's Digital Decade Policy Programme 2030, this methodology is of particular importance. In particular, the Digital Decade establishes the following target: "*all populated areas are covered by next-generation wireless high-speed networks with performance at least equivalent to that of 5G*" [6]. The current definition of the KPI for 5G target monitoring is "*5G coverage, measured as the percentage of populated areas covered by at least one 5G network regardless of spectrum band used*"[7]. However, not taking into account the QoS provided under peak conditions makes this KPI inadequate for properly monitoring the 5G target. This has already been identified in the Digital Economy and Society Index 2022 report and restated in the Final Report on Broadband Coverage in Europe 2022[8] following an EU-wide exercise on Digital Decade target monitoring. Namely, it is not sufficient to consider merely the *radio signal coverage* of 5G networks: it is vitally important to estimate the *performance* of 5G networks in terms of QoS under peak-time[9] conditions.

The existing BEREC Guidelines do not fully address mapping of 5G QoS KPIs, as they only make it "mandatory to map mobile broadband service availability per technology (3G/4G/5G)"[3]. The Mapping Annex of the Guidelines on State Aid[4] by contrast makes mandatory the mapping of mobile and FWA service performance in terms of expected peak end-user speeds, but offers insufficiently detailed guidance on how to calculate those speed estimates to ensure a reliably harmonized and comparable 5G QoS KPI mapping across MNOs and MSs.

To address these gaps, this methodology aims to be a prescriptive and detailed guide for quantifying both (i) **5G theoretical radio coverage**, reflecting service availability corresponding to a received signal strength (RSS) threshold and (ii) **5G QoS coverage**, in terms of estimated peak- end-user speeds in the downlink (DL) and uplink (UL).

This methodology is concerned solely with QoS-1[10] indicators to characterize the theoretical performance of 5G networks. In order to calculate a theoretical estimate of 5G QoS-1 end-user speeds, it adopts a low-complexity and transparent modelling approach and relies on nominal parameter values wherever appropriate, rather than detailed network-specific operational configurations.

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[6] Decision (EU) 2022/2481 of the European Parliament and of the Council of 14 December 2022 establishing the Digital Decade Policy Programme 2030 (OJ L 323/4, 19.12.2022).

[7] Commission Implementing Decision (EU) 2023/1353 of 30 June 2023 setting out key performance indicators to measure the progress towards the digital targets established by Article 4(1) of Decision (EU) 2022/2481 of the European Parliament and of the Council (OJ L 168/48 2023).

[8] "Final Report on Broadband Coverage in Europe 2022: Mapping progress towards the coverage objectives of the Digital Decade", European Commission, Directorate-General of Communications Networks, Content & Technology, doi: 10.2759/909629.

[9] *cf.* definition as "time of the day with a typical duration of one hour where the network load usually has its maximum" in BoR (20) 165

[10] The European Broadband Mapping project developed three data categories for Quality of Service (QoS). QoS-1 is a *calculated* metric that characterizes the theoretical network performance. By contrast, QoS-2 and QoS-3 are the *measured* provision and experience of service, respectively. QoS-2 is obtained using measurements via panel probes or drive tests which exclude the end-user's environment, whereas QoS-3 measurements include the end-user's environment, e.g. via online speed tests. *cf.* BoR (20) 42, § 2.1

This reflects a methodological trade-off, favouring transparency and comparability over a high-fidelity match between the theoretically estimated 5G QoS-1 and live measured 5G QoS-2/3 performance. Importantly, the selected approach addresses the key goals of:

(i) straightforward **comparability** of the 5G QoS mapping data across MSs;
(ii) **transparency and understandability** of the 5G QoS mapping data across the spectrum of potential end-users [11]; and
(iii) **applicability to both existing and planned** 5G network infrastructure deployments (in the context of state aid).

Finally, the results of this work can serve as an important input to inform the review of the Digital Decade Policy Programme, planned for 2026, without prejudice to possible decisions on existing, new or revised KPIs.

1.2 Preliminaries

5G wireless networks may offer a mobile broadband service (**mobile networks**) and/or fixed wireless access service (**FWA networks).** This methodology assumes that mobile and FWA 5G deployments are *separate*, such that a 5G MNO does *not* use common spectrum resources to jointly serve mobile and FWA users.[12]

[**Invitation to feedback**: Please see questions 7 and 8 in the public consultation questionnaire, concerning the issue of mapping resolution per frequency band range.]

This methodology is concerned with:

- **territorial mapping** of **5G mobile networks**, calculating and reporting 5G radio coverage and 5G QoS coverage data on the basis of 20 m × 20 m grid pixels;

- **territorial mapping** of **5G FWA networks**, calculating and reporting 5G radio coverage and 5G QoS coverage data on the basis of 20 m × 20 m grid pixels and taking into account the number of premises located within each grid pixel[13] and the *declared percentage of premises served* by the 5G FWA network.

[11] i.e. ranging from national and EU-level agencies and public and private institutions involved in relevant policy, regulatory, and state-aid issues.
[12] In case an MNO is using a common operating frequency band for mobile and FWA services, the MNO must declare the spectrum resource partitioning between the two services, corresponding to a *fixed* mobile:FWA channel partitioning ratio of the channel bandwidth allocation for the mobile and FWA network, respectively. The 5G QoS mapping shall then be conducted as per §3 for the mobile and FWA networks in frequency band f_c separately, assuming a fraction of the total bandwidth in the operating band (relating to parameters B_c and $B^{TX}{}_c$), as determined by the declared mobile: FWA channel partitioning ratio. While dynamic resource sharing between mobile and FWA services is commonly used in live networks, for modelling purposes this methodology assumes a fixed bandwidth partitioning between mobile and FWA services, representing the typical proportion of resources in the operating frequency band allocated to mobile vs. FWA services under peak time conditions; the MNOs shall declare this ratio as a constant input parameter to enable separate and transparent 5G QoS-1 estimation per service.
[13] An address-level mapping of 5G FWA networks may be subsequently derived from the territorial mapping in a straightforward manner, i.e. by considering the addresses of the premises overlapping the grid pixels.

[**Invitation to feedback**: Please see question 9 in the public consultation questionnaire, concerning the issue of FWA mapping scope.]

5G networks may use operating frequency bands in the **5G-NR range FR1** (bands below 7.125 GHz) or **5G-NR range FR2** (bands above 24.25 GHz)[14]. These two frequency ranges have distinctly dissimilar radio propagation characteristics, with consequences for the design and performance of 5G mobile and FWA networks in these bands. Consequently, this methodology distinguishes between 5G deployments operating in 5G-NR FR1 and 5G-NR FR2 where necessary.

1.3 Methodology Overview

This methodology describes a detailed workflow for mapping the (i) **theoretical radio coverage** and (ii) **QoS coverage** of 5G mobile and/or FWA networks. Firstly, the theoretical 5G radio coverage, corresponding to an RSS estimate from the "best-server cell" based on radio propagation and link budget calculations is mapped as detailed in **§2**. A geographical mapping of 5G service availability may then be straightforwardly obtained by comparing the 5G radio coverage against a pre-defined RSS threshold. Secondly, the mapping of the 5G QoS coverage, in terms of estimated peak-time end-user DL/UL speeds is then derived from the 5G radio coverage mapping, as detailed in **§3.** Namely, the 5G radio coverage estimated as per **§2** is translated into an estimate of the performance of the 5G network in terms of QoS in **§3**, taking into account the operating channel bandwidth and a model for the fraction of the available cell resources allocated per user under peak-time conditions. The model of the multiuser sharing of the 5G cell capacity adopted in this methodology is based on: (i) peak-time cell load, for 5G mobile networks and (ii) peak-time oversubscription rate and the declared percentage of served "premises connected" in the network target area, for 5G FWA networks. An overview of the detailed technical workflow of the methodology is as follows:

This methodology assumes that each MS has a set of $\boldsymbol{M}$ MNOs operating within its territory area $\boldsymbol{A_{MS}}$ offering 5G mobile and/or FWA services, where each MNO uses a set of 5G-NR operating frequency bands $\boldsymbol{Q^m}=\{f_c^1, f_c^2, \ldots, f_c^{|Qm|}\}$. Let us define $\boldsymbol{A_{MS}^{m,f}}$ as the geographic area corresponding to the target 5G network area of MNO $m\in\boldsymbol{M}$ using frequency band f_c, where $\boldsymbol{A_{MS}^{m,f}}\subseteq\boldsymbol{A_{MS}}$. Accordingly, the resulting 5G radio coverage and QoS mapping data for frequency band fc shall be reported by the MNO m on a per-pixel basis, for those pixels in the MS area corresponding to the target 5G network area $\boldsymbol{A_{MS}^{m,f}}$. (Namely, if the MNO is offering nationwide 5G coverage, $\boldsymbol{A_{MS}^{m,f}}=\boldsymbol{A_{MS}}$**,** whereas for regional deployments $\boldsymbol{A_{MS}^{m,f}}\subset\boldsymbol{A_{MS}}$.)

In order to carry out 5G QoS mapping using this methodology, the NRA/OCA for the MS shall, for each of the $M=|\boldsymbol{M}|$ MNOs operating within its territory area $\boldsymbol{A_{MS}}$, require MNO $m\in\boldsymbol{M}$ to perform, for each 5G operating frequency band f_c used by the MNO:

(i) **radio propagation and link budget calculations as per §2.1**, to obtain a mapping over the target network area of the received signal strength from all BSs in the network, for the DL and UL;

[14] *cf.* 3GPP TS 38.101.

(ii) **determination of the "best-server cell" as per §2.2**, to obtain a mapping over the target network area of: the 5G serving BS, the serving beam (for f_c in the 5G-NR range FR2), and the set and number of premises potentially served by each BS in the network (for FWA networks);

(iii) **estimation of the 5G radio coverage as per §2.3**, to obtain a mapping over the target network area of: the RSS from the serving BS, in the DL and UL;

(iv) **estimation of the 5G SINR coverage as per §3.1**, to obtain a mapping over the target network area of: the signal-to-noise-and-interference ratio (SINR), in the DL and UL;

(v) **estimation of the 5G cell capacity as per §3.2**, to obtain a mapping over the target network area of: the maximum achievable per-user data rate given the channel bandwidth B^c in the operating band f_c and under the idealised assumption of only a single user being served by the serving cell at that location, in the DL and UL;

(vi) **estimation of the 5G QoS coverage as per §3.3**, to obtain a mapping over the target network area of: the peak-time per-user data rate given the channel bandwidth B^c in the operating band f_c, in the DL and UL.

The 5G mapping data that must be subsequently reported by MNO $m \in \boldsymbol{M}$ to the NRA/OCA is summarized in **§4.1**, along with the additional data that may be requested by the NRA/OCA for verification purposes. Finally, upon receiving 5G mobile and FWA mapping data from all M MNOs operating in the MS, the NRA/OCA shall aggregate the data as specified in **§4.2.**

2 5G Radio Coverage Mapping

2.1 Radio Propagation & Link Budget Calculation

The following steps are to be followed to obtain a mapping of the RSS from all BSs in the network, in the DL and UL, over the target 5G network area:

(i) perform radio propagation simulations for each BS transmitter $j \in \boldsymbol{J}$ over the target network area $\boldsymbol{A_{MS}^{m,f}}$, for the operating frequency band f_c of interest, with the following requirements:

a. assume that the UE receiver antenna sampling points $i \in \boldsymbol{I}$ are located at the centres of pixels defined by a 20 m × 20 m grid over the target network area;

b. assume all BS transmitter and UE receiver antennas to be located outdoors; ***for FWA networks***, assume the UE receiver antenna is placed above the rooftop in accordance with common deployment practice;

c. at each UE sampling location $i \in \boldsymbol{I}$, assume a nominal receiver antenna height of:

i. $h^{mobile}{}_{UE}$=1.5 m, ***for mobile networks***;

ii. $h^{FWA}{}_{UE}(i)$= [$h^{buildings}(i)$ + 1] m, i.e. 1 m above average rooftop height of the buildings within the 20 m × 20 m pixel corresponding to UE sampling location i, ***for FWA networks***;

d. the radio propagation model used:
   i. *must* be appropriate for:
      1. the topology of the target network area (i.e. level of urbanization, extent and type of environmental clutter),
      2. the operating frequency band *fc,*
      3. the cell size (i.e. macro-, micro-cell);
   ii. *should* be consistent with the radio propagation model used by the MNO in its routine planning of existing operational 5G network deployments in the target area;
   iii. *must* take into account digital terrain model data for the target network area;
   iv. ***for operating frequency bands in the 5G-NR range FR1***:
      1. is *recommended* to be a (semi-)deterministic site-specific model (e.g. based on ray-tracing), taking into account digital 3D data of the network environment including buildings,
      2. *may* be a (semi-)empirical statistical model, calibrated for the target network area;
   v. ***for operating frequency bands in the 5G-NR range FR2***:
      1. *must* be a (semi-)deterministic site-specific model (e.g. based on ray-tracing), taking into account digital 3D data of the network environment including buildings;
   vi. *should* be disclosed by the MNO for verification purposes per frequency band (this may include key model-specific parameters, as requested by the NRA/OCA *cf.* §4.1);

e. the radio propagation computation *may* be facilitated with any suitable tool, but the modelling functionality and settings *must* be equivalent to that of industry best-practice network planning tools;

Output:
Path loss $L^j(i)$ **[dB]** for each UE receiver sampling point $i \in \boldsymbol{I}$ in the target network area $\boldsymbol{A_{MS}^{m,f}}$, for each BS transmitter $j \in \boldsymbol{J}$.

[**Invitation to feedback**: Please see question 10 in the public consultation questionnaire, concerning the issue of radio propagation modelling assumptions.]

(ii) determine the shadow fading margin, $M_{shadowing}(i)$ [dB] for each UE sampling point i in the target network area $\boldsymbol{A_{MS}^{m,f}}$, for each BS transmitter $j \in \boldsymbol{J}$, assuming a cell-edge coverage probability $P_{cov\text{-}edge}$ of 95% and shadow fading standard deviation $\sigma_{shadowing}$ (reflecting the shadowing location variability) for the clutter type appropriate for the frequency band f_c and urbanization level at location i in the network deployment area:

a. $P_{cov-edge} = 1 - Q\left(\frac{M_{shadowing}}{\sigma_{shadowing}}\right)$

Output:
Shadow fading margin $M_{shadowing}(i)$ [dB] for each UE sampling point i in the target network area.

[**Invitation to feedback**: Please see question 11 in the public consultation questionnaire, concerning the required value of cell-edge coverage probability]

(iii)perform a link budget calculation to obtain the received signal strength $RSS^j_{DL}(i)$ [dB] and $RSS^j_{UL}(i)$ [dB] in the DL and UL, respectively, for each UE sampling point $i \in \boldsymbol{I}$ in the target network area $\boldsymbol{A_{MS}^{m,f}}$, for each BS $j \in \boldsymbol{J}$, given by:

- $RSS^j_{DL}(i) = EIRP^j_{DL} - L^j(i) - M_{shadowing}(i) + G^{UE}$, and
- $RSS^j_{UL}(i) = EIRP^j_{UL} - L^j(i) - M_{shadowing}(i) + G^{BS}$, where:
- G_{BS} [dB] is the effective antenna gain at the BS taking into account the BS antenna radiation pattern (and including any terminal and antenna feeding losses);
- G_{UE} [dB] is the effective antenna gain at the UE, taking into account the UE antenna radiation pattern (and including any terminal and antenna feeding losses);
- $EIRP^j_{\mathrm{DL}}$ and $EIRP_{\mathrm{UL}}$ [dBm] are the effective isotropic radiated power by BS transmitter $j \in \boldsymbol{J}$ in the DL and a UE transmitter in the UL, respectively.

Output:
Received signal strength $RSS^j_{\mathrm{DL}}(i)$ **[dBm] and** $RSS^j_{\mathrm{UL}}(i)$ **[dBm] in the DL and UL**, respectively, for each UE sampling point $i \in \boldsymbol{I}$ in the target network area $\boldsymbol{A_{MS}^{m,f}}$, for each BS $j \in \boldsymbol{J}$.

(iv)additional considerations ***for operating frequency bands in the 5G-NR range FR2***:

a. given the use of directional beamforming in this frequency range, the path loss and link budget calculation *must* be performed separately for each combination of candidate antenna beams in the codebooks $\boldsymbol{C^{BS}}$ and $\boldsymbol{C^{UE}}$ at the BS and UE, respectively, taking into account the 3D spatial structure of the multipath channel obtained in the radio propagation simulations from §2.1-(i) and the 3D antenna radiation pattern and orientation of each candidate beam;
b. the codebook sizes assumed at the BS and UE, i.e. number of candidate beams $|\boldsymbol{C^{BS}}|$ and $|\boldsymbol{C^{UE}}|$, respectively, *must* be disclosed by the MNO per FR2 frequency band;
c. the received signal strength shall thus be calculated for each candidate *beam pair link* $\{p,q\}$ where $p \in \boldsymbol{C^{BS}}$ and $q \in \boldsymbol{C^{UE}}$;

Output:
Received signal strength $RSS^j_{\mathrm{DL}}(i,p,q)$ **[dBm] and** $RSS^j_{\mathrm{UL}}(i,p,q)$ **[dBm] in the DL and UL**, respectively, for UE sampling point $i \in \boldsymbol{I}$ in the target network area $\boldsymbol{A_{MS}^{m,f}}$, for each BS $j \in \boldsymbol{J}$ and for each candidate beam pair link $\{p \in \boldsymbol{C^{BS}}, q \in \boldsymbol{C^{UE}}\}$.

2.2 5G Serving Base Station Determination

The following steps are to be followed to obtain a mapping of the serving BS over the target 5G network area:

(i) determine the serving ("best server cell") BS $j^*\in\boldsymbol{J}$ for each UE sampling point $i\in\boldsymbol{I}$ in the target network area $\boldsymbol{A_{MS}}^{\boldsymbol{m,f}}$ as the BS providing the best 5G radio signal coverage[15] to that UE sampling point:

○ ***for operating frequency bands in the 5G-NR range FR1***:

- $j^*(i) = \underset{j}{\operatorname{argmax}}\, RSS_{DL}^{j}(i)$;

Output:
Serving BS $j^*(i)$ for each UE receiver sampling point $i \in \boldsymbol{I}$ in the target network area $\boldsymbol{A_{MS}}^{\boldsymbol{m,f}}$.

○ ***for operating frequency bands in the 5G-NR range FR2***:

- $j^*(i) = \underset{j}{\operatorname{argmax}}\, RSS_{DL}^{j}\left(i, p_j^*(i), q_j^*(i)\right)$,

  where the best beam pair link $\{p_j^*\in\boldsymbol{C^{BS}}, q_j^*\in\boldsymbol{C^{UE}}\}$ for each BS $j\in\boldsymbol{J}$ is given by $\{p_j^*(i), q_j^*(i)\} = \underset{p,q}{\operatorname{argmax}}\, RSS_{DL}^{j}(i,p,q)$

- determine the serving beam pair link $\{p^*\in\boldsymbol{C^{BS}}, q^*\in\boldsymbol{C^{UE}}\}$ on the serving BS as $\{p^*(i), q^*(i)\} = \underset{p,q}{\operatorname{argmax}}\, RSS_{DL}^{j^*}(i,p,q)$;
- determine whether the serving beam pair link $\{p^*(i)\in\boldsymbol{C^{BS}}, q^*(i)\in\boldsymbol{C^{UE}}\}$ is providing line-of-sight (LOS) or non-LOS (NLOS) coverage by comparing the pointing orientation of the BS serving beam $p^*(i)$ with the geometric LOS direction between the serving BS and UE, for each UE sampling point $i\in\boldsymbol{I}$;

Output:
Serving BS $j^*(i)$**, serving beam pair link** $\{p^*(i), q^*(i)\}$, for each UE receiver sampling point $i\in\boldsymbol{I}$ in the target network area $\boldsymbol{A_{MS}}^{\boldsymbol{m,f}}$.

[15] Note that selecting the "best server cell" based on DL signal strength is consistent with the use of DL reference signal measurements (i.e. SS-RSRP) for initial access/handover decisions in practice.

(ii) ***for FWA networks***, additionally determine the subset of premises $\boldsymbol{Z^j} \in \boldsymbol{Z}$ in the target network area $\boldsymbol{A_{MS}^{m,f}}$ that are potentially served by each BS $j \in \boldsymbol{J}$ as the set of all premises located within the territorial grid pixels corresponding to the UE receiver sampling points $\boldsymbol{I^j} \in \boldsymbol{I}$ that have BSj as their serving BSj^*:

- define $\boldsymbol{Z}$ as the set of premises (with corresponding address coordinates) within the target network area $\boldsymbol{A_{MS}^{m,f}}$;
- $\boldsymbol{I^j} = \{i: j^*(i) = j\}$;
- define $\boldsymbol{Z^j}$ as the subset of premises with address coordinates located within the grid pixels corresponding the UE sampling points in the set $\boldsymbol{I^j}$;
- number of premises **S(j)** potentially served by each BS $j \in \boldsymbol{J}$ is given by the size of $\boldsymbol{Z^j}$:
  - $S(j) = |\boldsymbol{Z^j}|$;

Output:

Set and number of premises potentially served by BS j**,** $\boldsymbol{Z^j}$ and $S(j)$, respectively, for each BS j ∈ **J** in the target network area $\boldsymbol{A_{MS}^{m,f}}$.

2.3 5G Signal Strength Estimation

The following steps are to be followed to obtain a mapping of 5G radio coverage from the serving BS, in the DL and UL, over the target 5G network area:

(i) calculate the received signal strength $RSS_{DL}(i)$ [dBm] and $RSS_{UL}(i)$ [dBm] in the DL and UL, respectively, for each UE sampling point $i \in \boldsymbol{I}$ in the target network area $\boldsymbol{A_{MS}^{m,f}}$, as provided by its serving BS $j^* \in \boldsymbol{J}$, as given by:

- ***for operating frequency bands in the 5G-NR range FR1***:

  $RSS_{DL}(i) = RSS_{DL}^{j^*}(i)$, and $RSS_{UL}(i) = RSS_{UL}^{j^*}(i)$;

- ***for operating frequency bands in the 5G-NR range FR2***:

  $RSS_{DL}(i) = RSS_{DL}^{j^*}(i, p^*, q^*)$, and $RSS_{UL}(i) = RSS_{UL}^{j^*}(i, p^*, q^*)$, where $\{p^*, q^*\}$ is the serving beam pair link on the serving BS;

Output:

Received signal strength $RSS_{DL}(i)$ [dBm] and $RSS_{UL}(i)$ [dBm] in the DL and UL, respectively, for each UE sampling point $i \in \boldsymbol{I}$ in the target network area $\boldsymbol{A_{MSm,f}}$.

(ii) 5G service availability *may* be defined as a binary value for each UE sampling point $I \in \boldsymbol{I}$ in the target network area $\boldsymbol{A_{MS}^{m,f}}$, by comparing $RSS_{DL}(i)$ and $RSS_{UL}(i)$ against a *5G radio coverage threshold*; to be consistent with this methodology, the 5G radio coverage threshold may be defined as the minimum RSS corresponding to the minimum SINR assumed in §3.2 (i.e., corresponding to the network being able to deliver a wireless broadband speed of more than 0 Mbps at that UE location).

3 5G QoS Mapping

3.1 SINR Estimation

The following steps are to be followed to obtain a mapping of the SINR coverage, in the DL and UL, over the target 5G network area:

(i) calculate the signal-to-interference-and-noise ratio $SINR_{DL}(i)$ [dB] and $SINR_{UL}(i)$ [dB] in the DL and UL, respectively, for each UE sampling point $i \in \boldsymbol{I}$ in the target network area $\boldsymbol{A_{MS}}^{m,f}$, as provided by its serving BS $j^* \in \boldsymbol{J}$, as given by:

$$SINR_{DL}(i) = RSS_{DL}(i) - I - N, \text{ and } SINR_{UL}(i) = RSS_{UL}(i) - I - N,$$

where:

- N [dBm]is the total noise power, calculated as $N = N_{thermal} + NF$, where:
  - $N_{thermal}$ [dBm] is the thermal noise power over the transmission bandwidth B^{TX}_c in the operating frequency band f_c, given by, $N_{thermal} = 10\log_{10}(\, k_B T B_c^{TX})$ where k_B is the Boltzmann constant and T [K] is assumed to be room temperature (i.e. assume a thermal noise power density of -174 dBm/Hz);
  - NF [dB] is the receiver noise figure; assume the nominal value NF=7 dB;
- I [dB] is the interference margin; assume the nominal value I=3 dB;

Output:
Signal-to-interference-and-noise ratio $SINR_{DL}(i)$ [dB] and $SINR_{UL}(i)$ [dBm] in the DL and UL, respectively, for each UE sampling point $i \in \boldsymbol{I}$ in the target network area $\boldsymbol{A_{MS}}^{m,f}$.

3.2 Cell Capacity Estimation

Let us define the cell capacity $R^{cell}_{DL}(i)$ [Mbps] and $R^{cell}_{UL}(i)$ [Mbps] as the maximum achievable data rate in the DL and UL, respectively, at the UE location $i \in \boldsymbol{I}$, given $SINR_{DL}(i)$ [dB] and $SINR_{UL}(i)$ [dB] and assuming that the UE at i is allocated by its serving cell $j^*(i)$ all the available resource blocks (RBs) over the transmission bandwidth B^{TX}_c in the operating frequency band f_c (i.e. assuming no other UEs are connected to the serving BS).

The following steps are to be followed to estimate the 5G cell capacity, in the DL and UL, over the target 5G network area:

[**Invitation to feedback**: Please see question 12 in the public consultation questionnaire, concerning the model for estimating the cell capacity.]

(i) calculate R^{DL}_{max} [Mbps] and R^{UL}_{max} [Mbps], the maximum supported 5G-NR data rate[16] in the DL and UL, respectively, as:

$$R^{DL}_{max} = 10^{-6} \times Q^{DL}_{m} v_{DL} F^{TDD}_{DL} F^{sc} R^{MAX} \frac{12 \times N^{C}_{RB}}{T^{\mu}_{sym}} (1 - OH_{DL}),$$

$$R^{UL}_{max} = 10^{-6} \times Q^{UL}_{m} v_{UL} F^{TDD}_{UL} F^{sc} R^{MAX} \frac{12 \times N^{C}_{RB}}{T^{\mu}_{sym}} (1 - OH_{UL}),$$

where:

- Q^{DL}_{m} [bits/symbol] and Q^{UL}_{m} [bits/symbol] is the maximum supported modulation order in the DL and UL, respectively; assume the values Q^{DL}_{m}=8 and Q^{UL}_{m} =6 (corresponding to 256-QAM in the DL and 64-QAM in the UL);
- v_{DL} and v_{UL} are the number of spatially multiplexed layers in the MIMO configuration in the DL and UL, respectively; assume the nominal[17] values v_{DL}=4 and v_{UL}=2 (corresponding to 4x4 SU-MIMO in the DL and 2x2 SUMIMO in the UL);

[**Invitation to feedback**: Please see question 14 in the public consultation questionnaire, concerning the issue of MIMO configuration.]

- F^{TDD}_{DL} and F^{TDD}_{UL} are TDD (time division duplexing) factors corresponding to the DL:UL ratio in the 5G-NR TDD frame structure configuration; for TDD channels assume a nominal [18] 3:1 ratio of DL:UL, i.e. F^{TDD}_{DL}=0.75 and F^{TDD}_{UL}=0.25; for FDD (frequency division duplexing) channels, F^{TDD}_{DL} and F^{TDD}_{UL} take the values of 1 or 0;

[**Invitation to feedback**: Please see question 13 in the public consultation questionnaire, concerning the issue of nominal TDD DL:UL ratio.]

- F^{SC} is a scaling factor; assume F^{SC}=1;
- R^{MAX} is a maximum code rate; assume R^{MAX}=948/1024;
- T^{μ}_{sym} is the OFDM symbol duration assuming 5G-NR numerology μ, given by $T^{\mu}_{sym}=10^{-3}/(14\times2^{\mu})$;

  assume the nominal 5G-NR numerology:
  - ***for operating frequency bands in the 5G-NR range FR1***: μ=1, with the subcarrier spacing *SCS*=30 kHz, supporting channel bandwidths up to B_c=100 MHz;
  - ***for operating frequency bands in the 5G-NR range FR2***: μ=3, with the subcarrier spacing *SCS*=120 kHz, supporting channel bandwidths up to B_c=400 MHz;

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[16] *cf.* 3GPP TS 38.306.
[17] Alternatively, the MNO may use the operational values of the MIMO configuration in the network deployment, but must explicitly declare this with the submission of 5G mapping data.
[18] Alternatively, the MNO may use the operational value of the UL:DL ratio corresponding to the TDD frame structure configuration in the network deployment, but must explicitly declare this with the submission of 5G mapping data.

- N^c_{RB} is the maximum RB allocation[19] in channel bandwidth[20] B_c with 5G-NR numerology μ;
- OH_{DL} and OH_{UL} represent a signalling overhead in the DL and UL, respectively; assume the values OH_{DL}={0.14, 0.18} and OH_{UL}={0.08, 0.10} for operating frequency bands in the 5G-NR range {FR1, FR2}.

(ii) estimate the cell capacity $R^{cell}{}_{DL}(i)$ [Mbps] and $R^{cell}{}_{UL}(i)$ [Mbps] in the DL and UL, respectively, for each UE sampling point $i \in \boldsymbol{I}$ in the target network area $\boldsymbol{A_{MS}^{m,f}}$, using the following *truncated and attenuated Shannon bound* formula[21]:

$$R_{DL}^{cell}(i) = \begin{cases} B_c^{TX} \alpha_{DL} \log_2(1 + SINR_{DL}(i)) v_{DL} F_{DL}^{TDD}, & \text{for } SINR_{min} \le SINR_{DL}(i) \le SINR_{max}^{DL} \\ R_{max}^{DL}, & \text{for } SINR_{DL}(i) > SINR_{max}^{DL} \\ 0 & \text{for } SINR_{DL}(i) < SINR_{min} \end{cases},$$

$$R_{UL}^{cell}(i) = \begin{cases} B_c^{TX} \alpha_{UL} \log_2(1 + SINR_{UL}(i)) v_{UL} F_{UL}^{TDD}, & \text{for } SINR_{min} \le SINR_{UL}(i) \le SINR_{max}^{UL} \\ R_{max}^{UL}, & \text{for } SINR_{UL}(i) > SINR_{max}^{UL} \\ 0 & \text{for } SINR_{UL}(i) < SINR_{min} \end{cases},$$

where:

- $B^{TX}{}_c$ [MHz] is the transmission bandwidth, given the channel bandwidth B_c in operating frequency band f_c, as specified in Tables 1.1 and 1.2 below for the 5G-NR range FR1 and FR2, respectively;
- α_{DL} and α_{UL} are the attenuation factors representing implementation losses in the DL and UL, respectively; assume the nominal values[22] α_{DL}=0.6 and α_{UL}=0.55;
- $SINR_{min}$ [dB] is the minimum SINR of the codeset; assume $SINR_{min}$=-10 dB;
- $R^{DL}{}_{max}$ [Mbps] and $R^{UL}{}_{max}$ [Mbps] are defined as the maximum throughput of the codeset[23] in the DL/UL, given by the maximum supported 5G-NR data rate in the DL/UL as specified in 3GPP TS 38.306 and detailed in §3.2-(i) above.
- $SINR^{DL}{}_{max}$ [dB] and $SINR^{UL}{}_{max}$ [dB] are the SINR in the DL/UL at which $R^{DL}{}_{max}$ and $R^{UL}{}_{max}$ are reached, respectively;
- note that $SINR_{DL}(i)$ *and* $SINR_{UL}(i)$ must be converted from [dB] to linear units when used in the above formulas;
- Fig. 1 illustrates R_{cell} vs. *SINR* in the DL and UL, for the examples of a 20 MHz channel in 5G-NR FR1 and 100 MHz channel in 5G-NR FR2 (assuming TDD with 3:1 ratio of DL:UL);

Output:

Estimated cell capacity $R^{cell}{}_{DL}(i)$ [Mbps] and $R^{cell}{}_{UL}(i)$ [Mbps] in the DL and UL, respectively, for each UE sampling point $i \in \boldsymbol{I}$ in the target network area $\boldsymbol{A_{MS}^{m,f}}$.

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[19] *cf.* 3GPP TS 38.101-1(Table 5.3.2-1) for FR1 and 3GPP TS 38.101-2(Table 5.3.2-1) for FR2.

[20] For simplicity, if carrier aggregation is employed within given frequency band, base the calculation on the total bandwidth in the operating frequency band over all component carriers (i.e. neglect any aggregation overhead).

[21] *cf.* 3GPP TS 36.942 for LTE and 3GPP TS 38.921 for 5G-NR coexistence; this model is consistent with that used in e.g. the Ofcom report "Award of the 700 MHz and 3.6-3.8 GHz spectrum bands: Further consultation on modelling and technical parameters", 2020.

[22] *cf.* attenuation factors assumed for E-UTRA (4G) TDD in 3GPP TS 36.942.

[23] Setting a maximum throughput is necessary to ensure proper truncation of the cell capacity vs. SINR function, given the highest modulation order supported by 5G-NR, i.e. up to 256-QAM in the DL and 64-QAM in the UL.

TABLE 1.1: TRANSMISSION BANDWIDTH CONFIGURATION FOR FR1 (*cf.* TABLE 5.3.2-1 IN 3GPP TS38.101-1 "MAXIMUM TRANSMISSION BANDWIDTH CONFIGURATION N_{RB}" & ASSUMING FR1 NUMEROLOGY μ=1 (*i.e.* SCS=30 KHZ))

B_c [MHz]	5	10	15	20	25	30	40	50	60	70	80	90	100
N^c_{RB}	11	24	38	51	65	78	106	133	162	189	217	245	273
B^{TX}_c [MHz] ($N^c_{RB} \times SCS \times 12$)	3.96	8.64	13.68	18.36	23.4	28.08	38.16	47.88	58.32	68.04	78.12	88.2	98.28

TABLE 1.2: TRANSMISSION BANDWIDTH CONFIGURATION FOR FR 2 (*cf.* TABLE 5.3.2-1 IN 3GPP TS38.101-2 "MAXIMUM TRANSMISSION BANDWIDTH CONFIGURATION N_{RB}" & ASSUMING FR2 NUMEROLOGY μ=3 (*i.e.* SCS=120 KHZ))

B_c [MHz]	50	100	200	400
N^c_{RB}	32	66	132	264
B^{TX}_c [MHz] ($N^c_{RB} \times SCS \times 12$)	46.08	95.04	190.08	380

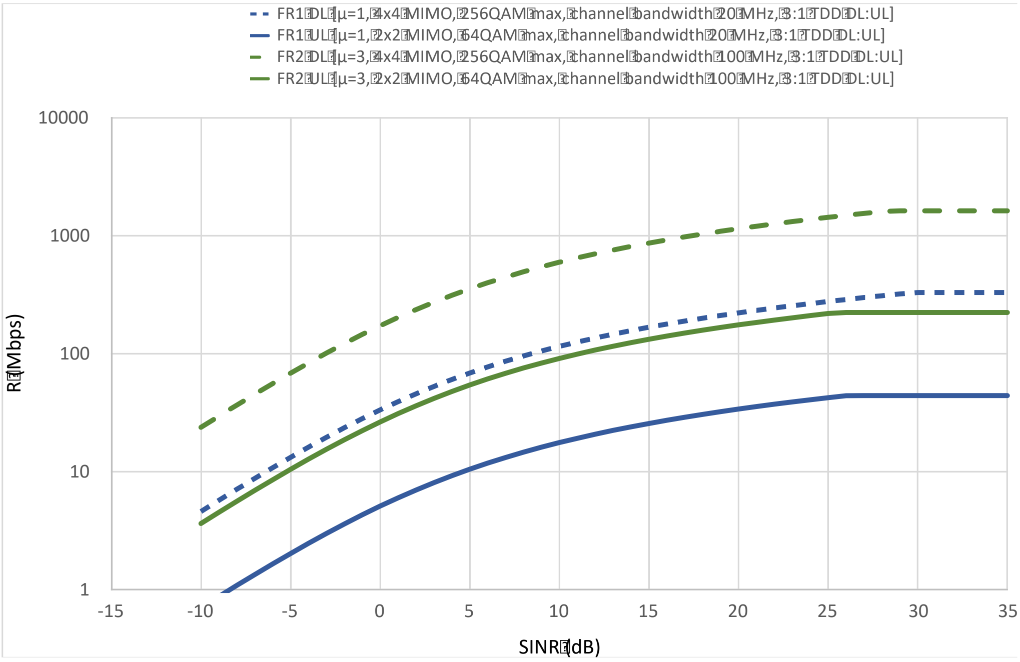

FIG. 1: R_{cell} vs. $SINR$ in DL and UL, for the examples of a 20 MHz channel in 5G-NR FR1 and a100 MHz channel in 5G-NR FR2 (assuming TDD with 3:1 ratio of DL:UL).

3.3 Peak-Time Per-User Data Rate Estimation

The cell capacity estimated in §3.2 corresponds to the achievable user data rate assuming no other UEs are connected to the serving BS (i.e. a "single-user cell" idealised system). In practice, a given BS will serve multiple associated UEs, such that the available cell capacity must be shared among those UEs. Let us define the per-user data rate $R^{user}_{DL}(i)$ [Mbps] and $R^{user}_{UL}(i)$ [Mbps] at the UE location $i \in \boldsymbol{I}$ as the fraction of the cell capacity $R^{cell}_{DL}(i)$ and $R^{cell}_{UL}(i)$ in the DL and UL, respectively, corresponding to the fraction of RBs in channel bandwidth B_c allocated to user i.

The following steps are to be followed to obtain the mapping of 5G QoS coverage in terms of estimated "peak-time" per-user data rate, in the DL and UL, over the target 5G network area:

[**Invitation to feedback**: Please see questions 15 and 16 in the public consultation questionnaire, concerning the model for estimating the per-user data rate in mobile and FWA networks, respectively.]

(i) (i) estimate the per-user data rate $R^{user}{}_{DL}(i)$ [Mbps] and $R^{user}{}_{UL}(i)$ [Mbps] in the DL and UL, respectively, for each UE sampling point $i \in \boldsymbol{I}$ in the target network area $\boldsymbol{A_{MS}}^{m,f}$, as:

$$R_{DL}^{user}(i) = \beta(i) R_{DL}^{cell}(i),$$

$$R_{UL}^{user}(i) = \beta(i) R_{UL}^{cell}(i),$$

where:

- $\beta(i)$ is the fraction of the RBs available over the transmission bandwidth $B^{TX}{}_{c}$ in the operating frequency band f_c that is allocated under "peak-time" conditions to UE i by its serving BS $j^*(i)$, and is estimated as:

- ***for mobile networks***:

  - $\beta(i) = 1 - \rho^{j^*(i)}$,
  where $\rho^{j^*(i)}$ is the cell load of UE i's serving cell j^*, defined as the average fraction of occupied RBs (i.e. sum of RBs allocated at the serving BS j^* to all active users in a reference period, divided by $N^{c}{}_{RB}$);
  - note that this estimate of β and its subsequent use in the estimation of the per-user data rates $R^{user}{}_{DL}$ and $R^{user}{}_{UL}$ in the formulas above is based on the so-called *processor sharing* or *equivalent circuit rate model* of a statistically-multiplexed channel with many bursty traffic sources (where ρ represents the average utilization of the cell capacity by a large number of intermittently active users) which has been shown to be robust for estimating the per-user data rate in shared wireless access networks[24,25];
  - assume the following nominal values of cell load under "peak-time" conditions:

$$\rho = \begin{Bmatrix} 0.9, & \text{for urban cells} \\ 0.5, & \text{for suburban cells} \\ 0.3 & \text{for rural cells} \end{Bmatrix}$$

  where the cell j^* is to be classified as urban/suburban/rural based on population density statistics[26] for the corresponding network area.

[**Invitation to feedback**: Please see question 17 in the public consultation questionnaire, concerning the issue of nominal cell load values for mobile networks under peak-time conditions.]

[24] A. Capone, M. Decina, A. Milan, and M. Petracca, "Modelling the Performance of High Capacity Access Networks for the Benefit of End-Users and Public Policies", *arXiv: https://arxiv.org/abs/2305.200352*, 2023.

[25] N. K. Shankaranarayanan, Z. Jiang, and P. Mishra, "Performance of a Shared Packet Wireless Network with Interactive Data Users", *Mobile Networks and Applications*, 2003.

[26] *cf.* definition of cities, towns and semi-dense areas, and rural areas corresponding to population densities in: "Applying the degree of urbanization", European Union/ FAO/UN-Habitat/OECD/The World Bank, 2021, doi:10.2785/706535.

- *for FWA networks*:

  - $\beta(i) = \frac{ORF}{\frac{\lambda}{100}\times S(j^*(i))\times N^{m-d}(i)}$, where:
    CDD
  - λ is the percentage of premises in the target area served ("premises connected") by the 5G FWA network, as declared by the MNO;
  - *ORF* is the oversubscription ratio factor; assume the nominal value of *ORF*=10, corresponding to the definition of peak-time conditions for fixed access networks[27] as when "*10% of the users are transmitting concurrently at the nominal peak rate provided by the operator to each of them, both downstream and upstream, which correspond to the usual oversubscription ratio definition*";
  - $S(j^*(i))$ is the number of premises that are potentially served by UE *i*'s serving cell j^* as defined in **§2.2-(ii);**
  - $N^{m-d}(i) \geq 1$ is the average number of FWA end-users per premises in the pixel corresponding to UE location *i*, taking into account that for FWA deployments with a shared rooftop receiver UE antenna for a multidwelling building, the estimated per-user data rate should be considered equally shared among the end users;
  - note that this estimate of β and its subsequent use in the estimation of the per-user data rates R^{user}_{DL} and R^{user}_{UL} in the formulas above is consistent with the capacity dimensioning of fixed access networks employing statistical multiplexing, where the oversubscription ratio represents the ratio of the maximum potential demand in the network to the contracted data rate provided by the fixed access network operator.

Output:
Estimated "peak-time" per-user data rate $R^{user}_{\mathrm{DL}}(i)$ [Mbps] and $R^{user}_{\mathrm{UL}}(i)$ [Mbps] in the DL and UL, respectively, for each UE sampling point $i \in \boldsymbol{I}$ in the target network area $A_{MS}^{m,f}$.

[27] *cf.* European Commission Communication from the Commission: Guidelines on state aid for broadband networks - Annex I Mapping (OJ C 36/01 2023), § 3.

4 Collection & Aggregation of 5G QoS Mapping Data

4.1 Collection of 5G QoS Mapping Data

The following 5G QoS mapping data is to be reported by MNO $m \in \boldsymbol{M}$ to the NRA/OCA for the MS, for each of its 5G-NR operating frequency bands $\boldsymbol{Q}^{m}=\{f_{c1}, f_{c2}, \ldots, f_{c|\boldsymbol{Q}m|}\}$:

(i) classification of 5G service offered[28] in the operating band f_c: ***mobile*** or ***FWA***;

(ii) channel **bandwidth** $\boldsymbol{B^c}$ in the operating band f_c;

(iii) when 5G radio coverage in terms of received signal strength is reported, **5G radio coverage** in terms of received signal strength $\boldsymbol{RSS_{DL}(i)}$ **[dBm] and** $\boldsymbol{RSS_{UL}(i)}$ **[dBm] in the DL and UL**, respectively, for each UE sampling point $i \in \boldsymbol{I}$ in the target network area $\boldsymbol{A_{MS}^{m,f}}$. RSS values are typically provided in aggregated form, classifying the estimations into predefined categories,[29] unless the national authority requires disaggregated data for verification or other purposes;

(iv) when 5G QoS coverage in terms of estimated data rate is reported, **5G QoS coverage** in terms of estimated **"peak-time" per-user data rate** $\boldsymbol{R^{user}_{DL}(i)}$ **[Mbps] and** $\boldsymbol{R^{user}_{UL}(i)}$ **[Mbps] in the DL and UL**, respectively, for each UE sampling point $i \in \boldsymbol{I}$ in the target network area $\boldsymbol{A_{MS}^{m,f}}$. Data rate values are typically provided in aggregated form, classifying the estimations into predefined categories, unless the national authority requires disaggregated data for verification or other purposes;

(v) ***for FWA networks***: the declared percentage of premises λ in the network target area $\boldsymbol{A_{MS}^{m,f}}$ served at the reported 5G QoS level.

Additionally, the following data **may be requested** by the NRA/OCA of a MS from MNO $m \in \boldsymbol{M}$ for basic verification purposes, depending on the national implementation of the methodology and regulatory needs:

(i) classification of operating channel as **TDD or FDD** (and whether FDD channel used for UL or DL);

(ii) **radio propagation model** used, including key model-specific parameters;

[28] In case the MNO is using a common operating frequency band for mobile and FWA services, the MNO must make a separate declaration of 5G QoS mapping data for the mobile and FWA networks and declare the *fixed* mobile: FWA spectrum resource partitioning ratio for the band f_c (*cf.* §1.2), i.e. resulting in correspondingly scaled values of B_c for the mobile and FWA datasets at f_c respectively.

[29] E.G. A binary classification approach can be used where RSSI values above a certain threshold indicate areas with adequate coverage ("served"), while values below this threshold denote areas with inadequate coverage ("unserved").

(iii) ***for f_c in 5G-NR FR2***: the **beam codebook sizes** assumed at the BS and UE: $|\boldsymbol{C}^{BS}|$ and $|\boldsymbol{C}^{UE}|$;

(iv) basic **UE characteristics**: assumed G_{UE} [dB] and $EIRP_{\mathrm{UL}}$ [dBm];

(v) basic **BS characteristics**, for each BS $j\in\boldsymbol{J}$ in the target network area $\boldsymbol{A_{MS}^{m,f}}$: location of cell site, information on antenna sectorization, height, and ground elevation, assumed G_{BS} [dB] and $EIRP^{j}_{\mathrm{DL}}$ [dBm];

(vi) characteristics of the **backhaul** (capacity, type), for each BS $j\in\boldsymbol{J}$ in the target network area $\boldsymbol{A_{MS}^{m,f}}$.

(vii) **serving BS** $j^{*}(i)$ for each UE receiver sampling point $i\in\boldsymbol{I}$ in the target network area $\boldsymbol{A_{MSm,f}}$;

(viii) ***for FWA networks***:
- **set and number of premises potentially served by BS** j**,** $\boldsymbol{Z}^{j}$ and $S(j)$, respectively, for each BS $j\in\boldsymbol{J}$ in the target network area $\boldsymbol{A_{MS}^{m,f}}$;
- the average **number of end-users assumed at the premises** $N^{m\text{-}d}(i)$ at the premises addresses corresponding to each UE receiver sampling point $i\in\boldsymbol{I}$ in the target network area $\boldsymbol{A_{MS}^{m,f}}$;

(ix) ***for mobile networks***: **cell load** ρ^{j} for each BS $j\in\boldsymbol{J}$.

Additionally, the following further data **may be requested** by the NRA/OCA of a MS from MNO *m* for in-depth verification purposes, depending on national implementation of the methodology and regulatory needs:

(i) **path loss** $L^{j}(i)$ [dB] **for each BS** $j\in\boldsymbol{J}$, for each UE receiver sampling point $i\in\boldsymbol{I}$ in the target network area $\boldsymbol{A_{MS}^{m,f}}$;
(ii) **shadow fading margin** $M_{shadowing}(i)$ [dB**]** for each UE sampling point i in the target network area $\boldsymbol{A_{MS}^{m,f}}$;
(iii) ***[for FWA networks***: the assumed **UE receiver height** $h^{FWA}{}_{UE}(i)$ for each UE receiver sampling point $i\in\boldsymbol{I}$ in the target network area $\boldsymbol{A_{MS}^{m,f}}$;
(iv) ***for f_c in 5G-NR FR1***: the **received signal strength from each BS** $j\in\boldsymbol{J}$, $RSS^{j}{}_{\mathrm{DL}}(i)$ [dBm] and $RSS^{j}{}_{\mathrm{UL}}(i)$ [dBm] in the DL and UL, respectively, for each UE sampling point $i\in\boldsymbol{I}$ in the target network area $\boldsymbol{A_{MS}^{m,f}}$; (v) ***for f_c in 5G-NR FR2***:

- **received signal strength from each BS** $j\in\boldsymbol{J}$ **and for each candidate beam pair link** $\{p\in\boldsymbol{C}^{BS}, q\in\boldsymbol{C}^{UE}\}$, $RSS^{j}{}_{\mathrm{DL}}(i,p,q)$ [dBm] and $RSS^{j}{}_{\mathrm{UL}}(i,p,q)$ [dBm] in the DL and UL, respectively, for each UE sampling point $i\in\boldsymbol{I}$ in the target network area $\boldsymbol{A_{MSm,f}}$;

- **serving beam pair link** $\{p^*(i), q^*(i)\}$, for each UE receiver sampling point $i \in \boldsymbol{I}$ in the target network area $\boldsymbol{A_{MS}}^{m,f}$;
- **classification as LOS or NLOS of serving beam pair link** $\{p^*(i), q^*(i)\}$ type, for each UE receiver sampling point $i \in \boldsymbol{I}$ in the target network area $\boldsymbol{A_{MS}}^{m,f}$;
- **digital 3D model of buildings and environmental clutter** used in the radio propagation simulations;
- **3D antenna radiation pattern** and orientation of each candidate beam in the BS and UE beam codebooks $\boldsymbol{C}^{BS}$ and $\boldsymbol{C}^{UE}$.

4.2 Aggregation of 5G QoS Mapping Data

Since each MNO independently reports its 5G QoS mapping data (per 5G-NR band) to the NRA/OCA of a given MS, the NRA/OCA shall then perform the aggregation on a spatial basis to produce composite maps for the MS.

[**Invitation to feedback**: Please see question 19 in the public consultation questionnaire, concerning the issue of inter-band carrier aggregation.]

Depending on the regulatory objective, one or more of the following aggregation methods may be used:

- **minimum per location:** taking the lowest QoS value reported by any MNO for each pixel. This approach would be suitable for identifying under-served areas where no operator delivers the required performance (e.g., for state-aid screening).
- **market-share-weighted average per location**: calculating a weighted average of the QoS values reported by all MNOs for each pixel, using each MNO’s national market share for the weighting factors.
- **maximum per location:** taking the highest QoS value reported by any MNO for each pixel. This reflects areas that are served by at least one operator at the given QoS level and is suitable for coverage reporting under the Digital Decade targets or for public transparency maps.

These aggregation methods enable the generation of harmonized national and cross-country maps, while preserving the individual reporting granularity and deployment strategies of each MNO.

Namely, upon receiving the 5G mobile and FWA mapping data {RSS^{m}_{DL}, RSS^{m}_{UL} and/or $R^{user,m}_{DL}$, $R^{user,m}_{UL}$} from each MNO $m \in M$ operating in the MS with territory area A_{MS}, the NRA/OCA shall compile and aggregate the data as follows:

(i) **for 5G mobile network**

mapping, taking into account the set M^{mobile} of all **MNOs** offering 5G mobile services in the MS and the set of 5G-NR operating frequency bands $Q^{mobile}=\{f_c^1, f_c^2, \ldots, f_c^{|Qmobile|}\}$ used for mobile service provisioning in the MS:

- the NRA/OCA shall compile the **5G mobile QoS dataset for the MS** over the territory area A_{MS} as the superset of **5G radio coverage data** {RSS^{m}_{DL}, RSS^{m}_{UL}} and **5G QoS coverage data** {$R^{user,m}_{DL}$, $R^{user,m}_{UL}$} reported by each MNO $m \in M^{mobile}$, for each 5G-NR mobile operating frequency band $f_c \in Q^{mobile}$;

- the NRA/OCA *may* aggregate the **5G mobile QoS dataset for the MS** over the territory area A_{MS} to generate a **5G radio coverage data** and **5G QoS coverage data** mapping for the MS per 5G-NR operating frequency band $f_c \in Q^{mobile}$, by:

    i. taking the ***minimum*** over the data {RSS^{m}_{DL}, RSS^{m}_{UL}} and {$R^{user,m}_{DL}$, $R^{user,m}_{UL}$} reported by each MNO $m \in M^{mobile}$ for each f_c;

    ii. alternatively, taking the ***weighted average*** over the data {RSS^{m}_{DL}, RSS_{mD}} and {$R_{user,mDL}$, $R_{user,mUL}$} reported by each MNO $m \in M_{mobile}$ for each f_c, weighted by the market share ratio of MNO $m \in M^{mobile}$ in the corresponding region;

    iii. alternatively, taking the ***maximum*** over the data {RSS^{m}_{DL}, RSS^{m}_{UL}} and {$R_{user,mDL}$, $R_{user,mUL}$} reported by each MNO $m \in M_{mobile}$ for each f_c.

(ii) **for 5G FWA network**

mapping, taking into account the set $\boldsymbol{M^{FWA}}$ of all **MNOs** offering 5G FWA services in the MS and the set of 5G-NR operating frequency bands $\boldsymbol{Q^{FWA}}=\{f_c^1, f_c^2, \ldots, f_c^{|QFWA|}\}$ used for FWA service provisioning in the MS:

- the NRA/OC shall compile the **5G FWA QoS dataset for the MS** over the territory area $\boldsymbol{A_{MS}}$ as the superset of **5G radio coverage data** $\{\boldsymbol{RSS^m_{DL}}, \boldsymbol{RSS^m_{UL}}\}$ and **5G QoS coverage data** $\{\boldsymbol{R^{user,m}_{DL}}, \boldsymbol{R^{user,m}_{UL}}\}$ reported by each MNO $m\in \boldsymbol{M^{FWA}}$, for each 5G-NR FWA operating frequency band $f_c\in\boldsymbol{Q^{FWA}}$;

- the NRA/OCA *may* aggregate the **5G FWA QoS dataset for the MS** over the territory area $\boldsymbol{A_{MS}}$ to generate a **5G radio coverage data** and **5G QoS coverage data** mapping for the MS per 5G-NR operating frequency band $f_c\in\boldsymbol{Q^{FWA}}$, by:

    i. taking the ***minimum*** over the data $\{\boldsymbol{RSS^m_{DL}}, \boldsymbol{RSS^m_{UL}}\}$ and $\{\boldsymbol{R^{user,m}_{DL}}, \boldsymbol{R^{user,m}_{UL}}\}$ reported by each MNO $m\in\boldsymbol{M^{FWA}}$ for each f_c;

    ii. alternatively, taking the ***weighted average*** over the data $\{\boldsymbol{RSS^m_{DL}}, \boldsymbol{RSS^m_{D}}\}$ and $\{\boldsymbol{R^{user,m}_{DL}}, \boldsymbol{R^{user,m}_{UL}}\}$ reported by each MNO $m\in\boldsymbol{M^{FWA}}$ for each f_c, weighted by the market share ratio of MNO $m\in\boldsymbol{M^{FWA}}$ in the corresponding region;

    iii. alternatively, taking the ***maximum*** over the data $\{\boldsymbol{RSS^m_{DL}}, \boldsymbol{RSS^m_{UL}}\}$ and $\{\boldsymbol{R^{user,m}_{DL}}, \boldsymbol{R^{user,m}_{UL}}\}$ reported by each MNO $m\in\boldsymbol{M^{FWA}}$ for each f_c.

Appendix A: List of Common & Nominal Parameter Values

- thermal noise power $N_{thermal}$ [dBm] : assume thermal noise power density of -174 dBm/Hz

- receiver noise figure NF [dBm]: assume the nominal value NF=7 dB

- interference margin I [dB]: assume the nominal value I=3 dB

- the maximum supported modulation order in the DL and UL $Q^{DL}{}_{m}$ and $Q^{UL}{}_{m}$ [bits/symbol]: assume the values $Q^{DL}{}_{m}$=8 and $Q^{UL}{}_{m}$ =6 (corresponding to 256-QAM in the DL and 64QAM in the UL)

- the number of spatially multiplexed layers in the MIMO configuration in the DL and UL v_{DL} and v_{UL}: assume the nominal values v_{DL}=4 and v_{UL}=2 (corresponding to 4x4 SU-MIMO in the DL and 2x2 SU-MIMO in the UL)

- DL:UL ratio in the 5G-NR TDD frame structure configuration $F^{TDD}{}_{DL}$ and $F^{TDD}{}_{DL}$: for TDD channels assume a nominal 3:1 ratio of DL:UL, i.e. $F^{TDD}{}_{DL}$=0.75 and $F^{TDD}{}_{DL}$=0.25; for FDD channels, $F^{TDD}{}_{DL}$ and $F^{TDD}{}_{DL}$ take the values of 1 or 0

- scaling factor F^{SC}: assume F^{SC}=1

- maximum code rate R^{MAX}: assume R^{MAX}=948/1024

- 5G-NR numerology μ: assume the nominal values μ=1 and μ=3 for operating frequency bands in the 5G-NR range FR1 and FR2, respectively

- signaling overhead in the DL and UL OH_{DL} and OH_{UL}: assume the values OH_{DL}={0.14,
- 0.18} and OH_{UL}={0.08, 0.10} for operating frequency bands in the 5G-NR range {FR1, FR2}

- attenuation factors representing implementation losses in the DL and UL α_{DL} and α_{DL}:
- assume the nominal values α_{DL}=0.6 and α_{UL}=0.55

- minimum SINR of the codeset $SINR_{min}$ [dB]: assume $SINR_{min}$=-10 dB

- cell load for mobile networks ρ: assume the nominal values under peak-time conditions of ρ={0.9, 0.5, 0.3} for {urban, suburban, and rural} cells

- oversubscription ratio factor for FWA networks ORF: assume the nominal value of ORF=10

[**Invitation to feedback**: Please see question 20 in the public consultation questionnaire, concerning nominal parameter values.]

Appendix B: Glossary

BS	base station (5G gNB)
DL	downlink
EU	European Union
FWA	fixed wireless access
LOS	line-of-sight
MNO	mobile network operator
MS	member state of the EU
NLOS	non-line-of-sight
NRA	national regulatory authorities
OCA	other competent authorities
RB	resource block
RSS	received signal strength
SINR	signal-to-interference-and-noise ratio
UE	user equipment
UL	uplink