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Abstractions for the DT gNB

Abstract

This document presents all available data structures for the construction of the gNB-DT, and explains some examples from the literature to identify the minimum data required for each of them. It defines the main entities which interact with the gNB, and those which participate in the process of extracting the data. In addition, the document includes some deployment options for the gNB-DT, and the different ways of obtaining the information for each case.

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Disclaimer

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List of Acronyms

3GPP	3rd Generation Partnership Project
4G	4th Generation
5G	5th Generation
5GC	5G Core
AF	Application Function
AMF	Access and Mobility Management Function
BS	Base Station
CP	Control Plane
CU	Central Unit
DN	Data Network
DT	Digital Twin
DU	Distributed Unit
eNB/eNodeB	Evolved Node B
E-UTRA	Evolved UMTS Terrestrial Radio Access
gNB/gNodeB	Next Generation Node B
IETF	Internet Engineering Task Force
ML	Machine Learning
NEF	Network Exposure Function
NG	Next Generation
NG-RAN	Next Generation RAN
NR	New Radio
NWDAF	Network Data Analytics Function
OAM	Operations, Administration and Maintenance
PRB	Physical Resource Block
QoS	Quality of Service
RAN	Radio Access Network
RB	Radio Bearer
RRM	Radio Resource Management
SMF	Session Management Function

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SNR	Signal to Noise Ratio
UE	User Equipment
UMTS	Universal Mobile Telecommunications System
UP	User Plane
UPF	User Plane Function
vRAN	Virtualization of RANs

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Executive Summary

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1. Introduction

The eNodeB from E-UTRA (4G) networks are replaced in 5G by the gNodeB. It provides user and control plane protocol terminations towards the User Equipments (UEs), connecting them to the 5G Core (5GC), where all the requested services are provided. Among its functionalities, one can also highlight the management of the radio communication to/from all the UEs located in its range. In addition, the gNB supports the division or split of its functionalities, based on its protocol stack and the type of data (user or control).

As one can see, the gNB plays a key role in 5G communications, so it is a good target to research and improve the performance of the network.

By other hand, digital twining is a method that replicates the functions of a physical system or entity in a digital or virtual copy, which is called Digital Twin (DT). Its functionalities are aligned with one or more of the following objectives: monitoring, simulating, real-time improvings or predicting. To achieve them, Machine Learning (ML) models are widely used by the developers.

Due to its huge effectiveness, this method is acquiring a significant popularity in the research area. So much so that it has also begun to be deployed in many different fields, such as networking, focusing on the entire network, a part of it, or even a specific block or node.

Hence, the objective is to implement a DT of the gNB from a 5G network to take advantage of all the possibilities and benefits that the DT technology provides. One important part to develop this system is to know the available information about the gNB, the places where it is stored and how to extract it.

In this document, it is proposed some deployment options to implement the gNB-DT system, and the existing vias to extract the necessary data are discussed. Additionally, the data structures that are available in the 5G network that can be useful to generate any gNB-DT are identified and listed, including extra data which is not considered in the standards. This paper concludes with some examples from the literature applied to this case, identifying the minimum data required to carry out them.

2. gNB architecture (5G/NG - RAN)

The gNodeB (gNB) is a New Generation Radio Access Network (NG-RAN) node, inside a cellular network; it is the equivalent of the Base Station (BS) of traditional cellular networks. The node can be physical or virtual.

A gNB provides connectivity between the 5G Core (5GC) and the User Equipments (UEs) inside its coverage area, known as cell. It is connected to the 5GC by means of the NG interfaces [1]. More specifically, to the AMF (Access and Mobility Management Function) and the UPF (User Plane Function) through the NG-C and NG-U interfaces, respectively.

The functions of the mentioned blocks are summarised in the following figure (Figure 2-1) from [2]. A deep explanation of the 5GC entities is going to be carried out in the following section.

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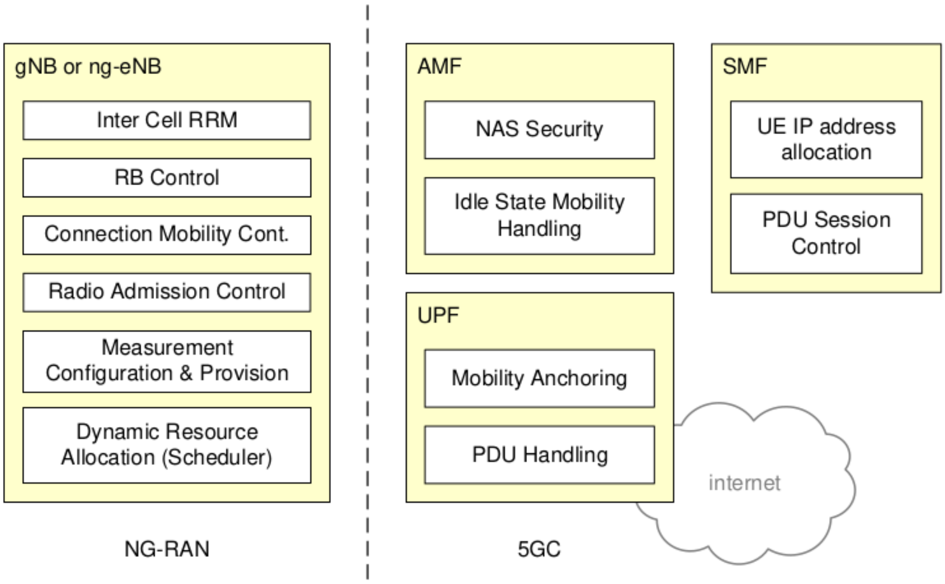

FIGURE 2-1: MAIN FUNCTIONALITIES OF SOME 5G ENTITIES [2].

One can also find the list with all functions of the gNB in [2]:

- Functions for Radio Resource Management: Radio Bearer Control, Radio Admission Control, Connection Mobility Control, Dynamic allocation of resources to UEs in both uplink and downlink (scheduling).
- IP and Ethernet header compression, uplink data decompression, encryption and integrity protection of data.
- Selection of an AMF at UE attachment when no routing to an AMF can be determined from the information provided by the UE.
- Routing of User Plane data towards UPF(s).
- Routing of Control Plane information towards AMF.
- Connection setup and release.
- Scheduling and transmission of paging messages.
- Scheduling and transmission of system broadcast information (originated from the AMF or OAM).
- Measurement and measurement reporting configuration for mobility and scheduling.
- Transport level packet marking in the uplink.
- Session Management.
- Support of Network Slicing.
- QoS Flow management and mapping to data radio bearers.
- Support of UEs in RRC_INACTIVE state.
- Distribution function for NAS messages.
- Radio access network sharing.
- Dual Connectivity.

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- Tight interworking between NR and E-UTRA.

The gNB can be splitted in a Central Unit (CU) and one or more Distributed Unit (DU), connected via F1 interfaces [3], dividing the different layers of the gNB, visualised in the Figure 2-2.

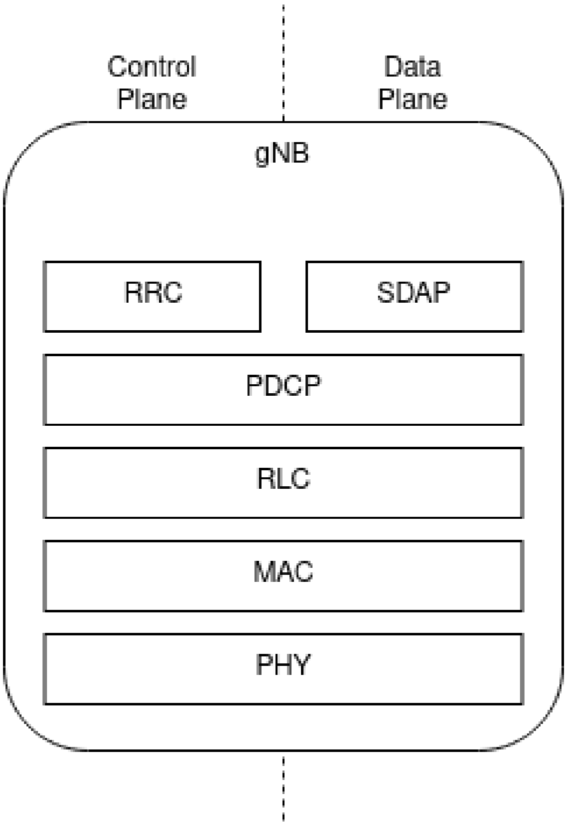

FIGURE 2-2: PROTOCOL LAYERS OF THE GNB.

By one hand, the gNB-DU hosts the RLC, MAC and PHY layers of the gNB.

The gNB-CU can also be separated into two logical parts, the Control Plane (CP) and the User Plane (UP):

- gNB-CU-CP: it hosts the RRC and the control plane part of the PDCP protocol. Is connected to the gNB-DU via F1-C interface.
- gNB-CU-UP: it hosts the user plane part of the PDCP and SDAP protocols. Is connected to the gNB-DU via F1-U interface.

Both are connected via the E1 interface [4]. The gNB-CU may consist of one gNB-CU-CP and multiple gNB-CU-UP. The structure is visualised in the Figure 2-3 from [5]:

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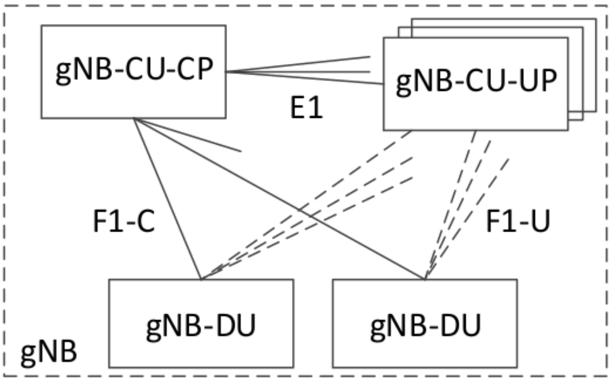

FIGURE 2-3: SCHEME OF THE GNB IN THE SPLITTED SCENARIO.

Additionally, a gNB is connected through the gNB-CU to another NG-RAN node via Xn interface [6] and to the 5GC via NG interface.

A detailed description on the splitted architecture is given by [5].

3. 5G Core (5GC) architecture

Now, it is the time to explain the architecture of the 5GC and the functionalities of the different blocks that composed it. The following figure (Figure 3-1) represents a scheme of the 5GC architecture, where DN refers to the Data Network.

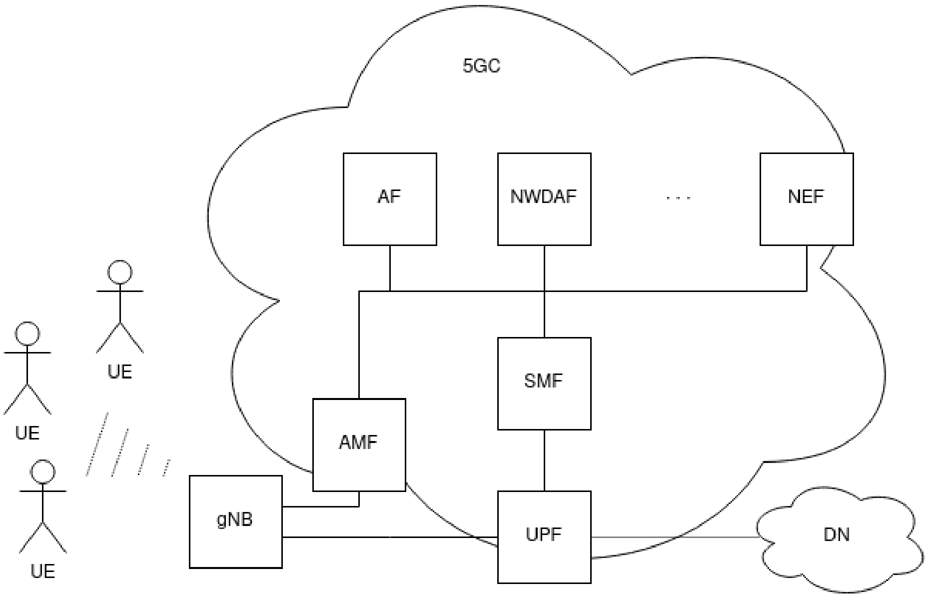

FIGURE 3-1: REPRESENTATION OF THE 5GC.

The main functionalities of each block are the following:

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- **AMF**: The Access and Mobility Management function (AMF) is in charge of managing the access of the UEs to the network to provide them the required services. In particular, its functionalities are: registration, connection, reachability and mobility management; access authentication and authorization; and transparent proxy for routing Session Management (SM) messages, among others.
- **UPF**: The User Plane Function (UPF) acts as a gate to the Data Network (DN). Its functionalities are mainly related to packet routing and forwarding. It also supports some QoS features.
- **SMF**: The Session Management Function (SMF), as its name indicates, is responsible for establishing and managing the sessions of the UEs. It also realices UE IP allocation and management tasks.
- **NWDAF**: The Network Data Analytic Function (NWDAF) collects data from other blocks to optionally perform analysis and expose the information (it supports the use of Machine Learning (ML) models). The data that is retrieved and the operations over it is not specified in the standards, so it is left to each particular operator.
- **NEF**: The Network Exposure Function (NEF) is mainly a gate to ensure security within communications between trusted and untrusted functions. In other words, it exposes the events from one side to the other in a safe way.
- **AF**: An Application Function (AF) is any other block in the 5GC that is not specified in the 3GPP standards and provides some services. If an AF is considered as trustworthy by the operator, it can directly interact with the other blocks from the 5GC. However, if it is not, the AF must interact with them via the NEF.

A more extensive explanation of these entities and others (which are optional or meaningless to be mentioned in this document) is detailed in [7], including the interfaces among them.

4. Data structures to recreate the gNB DT

After reviewing the functionalities of the gNB from the NG-RAN and the 5GC, we can proceed with our objective. As it is mentioned in the introduction, we aim to develop a Digital Twin (DT) of the gNB in order to further improve its performance.

A DT is a virtual copy of some structure, service or component, mainly physical, from a system. The copy must recreate the performance of the original object or, at least, part of it. This concept can be applied in different areas (such as industry [8], smart cities [9], healthcare [10],...) to exploit its advantages and nowadays, its popularity is suffering an exponential growth [11].

The purpose of the DT is the most common form of classifying them:

- Simulating: using some input parameters and the information of the original object to understand how it behaves under certain conditions.
- Monitoring: using real-time information about the original object to see its actual behaviour.
- Real-Time actions: based on the collected information, the DT must take some decisions and report them as fast as possible.
- Predicting: using information among a period of time to anticipate the behaviour at some future time.

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Another type of classification is based on the field where the DT is going to be applied. In our case, it is the networking field. For this kind of DTs, the IETF proposed a generic structure to deploy them [12], seen in Figure 4-1. However, it is not mandatory to strictly follow its approach.

```
+---------------------------------------------------------+
|   +--------+   +--------+         +--------+            |
|   | App 1  |   | App 2  |   ...   | App n  |   Application|
|   +--------+   +--------+         +--------+            |
+-------------^-------------------+-----------------------+
              |Capability Exposure| Intent Input
              |                   |
+-------------+-------------------v-----------------------+
|                        Instance of Digital Twin Network |
|  +--------+   +------------------------+   +--------+   |
|  |        |   | Service Mapping Models |   |        |   |
|  |        |   |  +------------------+  |   |        |   |
|  | Data   +--->  |Functional Models |  +---> Digital|   |
|  | Repo-  |   |  +-----+-----^------+  |   | Twin   |   |
|  | sitory |   |        |     |         |   | Entity |   |
|  |        |   |  +-----v-----+------+  |   |  Mgmt  |   |
|  |        <---+  |  Basic Models    |  <---+        |   |
|  |        |   |  +------------------+  |   |        |   |
|  +--------+   +------------------------+   +--------+   |
+--------^-----------------------------+------------------+
         |                             |
         | data collection             | control
+--------+-----------------------------v------------------+
|                    Physical Network                     |
|                                                         |
+---------------------------------------------------------+
```

FIGURE 4-1: GENERIC STRUCTURE OF A NETWORK DT REF.

In this document we are going to list the data structures that can be used to feed the DT. The list is very extensive and it is odd to see deployments using all data. The idea is to select those which fits better with the purpose that one gives to its gNB DT.

4.1. Possible deployments

It is important to be clear about the possible deployment options that one has to create the DT, in order to understand where we obtain the data from.

One idea is to connect our DT directly to the OAM, which is connected to the gNB and 5GC at the same time. This option allows to obtain data from the performance measurements that the OAM executes over all elements, and the state information that the OAM stores about them.

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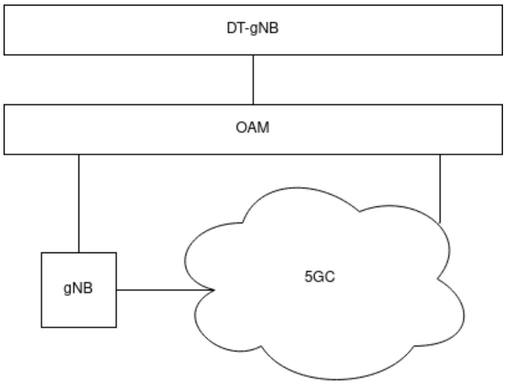

FIGURE 4-2: DEPLOYMENT OPTION 1.

Additionally, the DT can be deployed also inside the 5GC, as a NWDAF to collect, process and interpret the data, and some AF which get the processed data and take actions. This option can be separated into two different possibilities in function of the reliability given to the NWDAF block.

These deployments allow the DT to subscribe to the exposure events generated by the rest of blocks in the 5GC, which means, another way of obtaining information, in addition to through the OAM. However, the gNB does not generate these kinds of events.

Sending the information from the NWDAF to targets AFs also needs to be performed via exposure events.

If some block (either the NWDAF or an AF) is not trustworthy, they cannot directly subscribe to the events which expose the information; they must do it via the NEF.

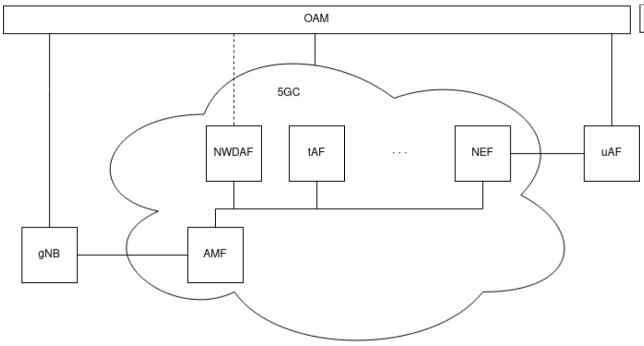

FIGURE 4-3: DEPLOYMENT OPTION 2.

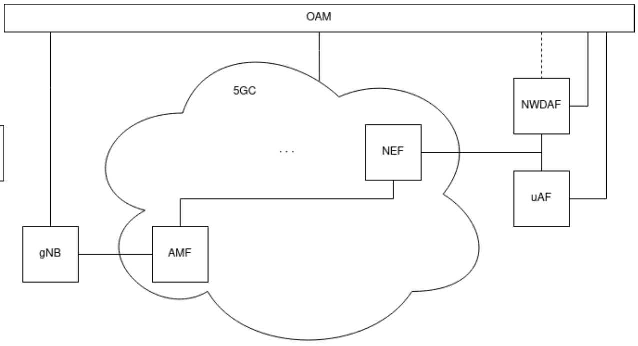

FIGURE 4-4: DEPLOYMENT OPTION 3.

In both images, tAF represents a trusted AF, and uAF, an untrusted AF. Additionally, the connections from the OAM to the untrusted blocks is optional, and if it does not appear, one can access the data of the OAM using the exposure events of a trusted NWDAF (connected to the 5GC) providing this information.

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4.2. Data structures available @gNB

Then, the only direct way of obtaining data from the gNB is through the OAM. It performs measurements over all blocks (including the gNB) and exposes the collected information.

In this subsection, the list of all possible performance measurements considered in the standard [13] that can be taken from the gNB is presented in Tables 4-1 to 4-3 [13]. Depending on the deployment of the gNB, they are different, as Table 4-2 and 4-3 shows.

Additionally, some of the measures are divided into sub-counters according to specific filter parameters detailed in [13].

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TABLE 4-1: MEASUREMENTS VALID FOR ALL POSSIBLE DEPLOYMENTS OF THE GNB.

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Group	Measure	Description
Packet Delay	DRB.AirIfDelayDl_Filter	Arithmetic mean delay over the air interface in DL.
	DRB.AirIfDelayDist.Bin_Filter	Distribution of delay over the air interface in DL.
	DRB.AirIfDelayUl_Filter	Arithmetic mean delay over the air interface in UL.
	DRB.RlcDelayUl_Filter	Arithmetic mean delay of RLC packets in UL.
	DRB.PdcpReordelayUl_Filter	Arithmetic mean PDCP reordering delay in UL.
	DRB.DelayDlNgranUeDist.Bin_Filter	Distribution of delay between NG-RAN and UE in DL.
	DRB.DelayUlNgranUeDist.Bin_Filter	Distribution of delay between NG-RAN and UE in UL.
	GTP.DelayDlPsaUpfNgranMean	Arithmetic mean delay of GTP packets between PSA UPF and NG-RAN in DL.
Radio resource utilization	RRU.PrbTotDl	Total usage (percentage) of physical resource block's (PRBs) in DL.
	RRU.PrbTotUl	Total usage (percentage) of physical resource block's (PRBs) in UL.
	RRU.PrbTotDlDist.BinX	Distribution of samples with total usage of PRBs in DL.
	RRU.PrbTotUlDist.BinX	Distribution of samples with total usage of PRBs in UL.
	RRU.PrbUsedDl	Average number of PRBs used in DL for data traffic.
	RRU.PrbAvailDl	Total number of PRBs in average available DL.
	RRU.PrbUsedUl	Average number of PRBs used in UL for data traffic.
	RRU.PrbAvailUl	Total number of PRBs in average available UL.
	RRU.MaxPrbUsedDl	Maximum number of PRBs used in DL for data traffic.
	RRU.MaxPrbUsedUl	Maximum number of PRBs used in UL for data traffic.
	RRU.PrbTotDlMimo	Total usage (percentage) of PRBs per cell for MIMO in DL.
	RRU.PrbTotUlMimo	Total usage (percentage) of PRBs per cell for MIMO in UL.
	RRU.PrbTotSdmDl	Total usage (percentage) of PDSCH PRBs based on statistical MIMO layers.
	RRU.PrbTotSdmUl	Total usage (percentage) of PUSCH PRBs based on statistical MIMO layers.
UE throughput	DRB.UEThpDl	Average UE throughput in DL.
	DRB.UEThpDlDist.Bin	Distribution of UE throughput in DL.
	DRB.UEThpUl	Average UE throughput in UL.
	DRB.UEThpUlDist.Bin	Distribution of UE throughput in UL.
	DRB.UEUnresVolDl	Percentage of DL data volume for UEs in the unrestricted cell.
	DRB.UEUnresVolUl	Percentage of UL data volume for UEs in the unrestricted cell.
RRC connection number	RRC.ConnMean	Mean number of users in RRC connected mode for each NR cell during each granularity period.
	RRC.ConnMax	Maximum number of users in RRC connected mode for each NR cell during each granularity period.
	RRC.InactiveConnMean	Mean number of users in RRC inactive mode for each NR cell during each granularity period.
	RRC.InactiveConnMax	Maximum number of users in RRC inactive mode during each granularity period.
PDU Session Mgmt	SM.PDUSessionSetupReq.SNSSAI	Number of PDU Sessions.
	SM.PDUSessionSetupSucc.SNSSAI	Number of PDU Sessions successfully setup.
	SM.PDUSessionSetupFail.Cause	Number of PDU Sessions failed to setup.

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	SM.MeanPDUSessionSetupReq.SNSSAI	Mean number of PDU Sessions allocated in the NRCellCU.
	SM.MaxPDUSessionSetupReq.SNSSAI	Maximum number of PDU Sessions allocated in the NRCellCU.
Mobility Mgmt – Inter-gNB handovers	MM.HoPrepInterReq	Number of legacy handover preparations requested by the source gNB.
	MM.HoPrepInterSucc	Number of successful legacy handover preparations received by the source NR cell CU.
	MM.HoPrepInterFail.cause	Number of failed legacy handover preparations received by the source NR cell CU.
	MM.HoResAlloInterReq	Number of legacy handover resource allocation requests received by the target NR cell CU.
	MM.HoResAlloInterSucc	Number of successful legacy handover resource allocations at the target NR cell CU.
	MM.HoResAlloInterFail.cause	Number of failed legacy handover resource allocations at the target NR cell CU.
	MM.HoExeInterReq	Number of outgoing legacy handover executions requested by the source gNB.
	MM.HoExeInterSucc	Number of successful legacy handover executions received by the source gNB.
	MM.HoExeInterFail.UeCtxtRelCmd.cause	Number of failed legacy handover executions for the source gNB.
	MM.HoExeInterReq.TimeMean.SNSSAI	Mean time of inter-gNB legacy handover executions during each granularity period.
	MM.HoExeInterReq.TimeMax.SNSSAI	Maximum time of inter-gNB legacy handover executions during each granularity period.
	MM.HoExeInterSSBSucc	Number of successful handover executions received by the source gNB per beam pair.
	MM.HoExeInterSSBFail.UeCtxtRelCmd.cause	Number of failed handover executions received by the source gNB per beam pair.
Mobility Mgmt – Intra-gNB handovers	MM.HoExeIntreReq	Number of outgoing intra gNB legacy handover executions requested by the source NRCellCU.
	MM.HoExeIntraSucc	Number of successful intra gNB legacy handover executions received by the source NRCellCU.
Mobility Mgmt – Handovers between 5GS and EPS	MM.HoOut5gsToEpsPrepReq	Number of preparations requested by the source gNB for the outgoing handovers from 5GS to EPS.
	MM.HoOut5gsToEpsPrepSucc	Number of successful preparations received by the source gNB for the outgoing handovers from 5GS to EPS.
	MM.HoOut5gsToEpsPrepFail.cause	Number of failed preparations received by the source gNB for the outgoing handovers from 5GS to EPS.
	MM.HoIncEpsTo5gsResAlloReq	Number of resource allocation requests received by the target gNB for handovers from EPS to 5GS.
	MM.HoIncEpsTo5gsResAlloSucc	Number of successful resource allocations at the target gNB for handovers from EPS to 5GS.
	MM.HoIncEpsTo5gsResAlloFail.cause	Number of failed resource allocations at the target gNB for handovers from EPS to 5GS.
	MM.HoOutExe5gsToEpsReq	Number of executions requested by the source gNB for handovers from EPS to 5GS.
	MM.HoOutExe5gsToEpsSucc	Number of successful executions at the source gNB for handovers from EPS to 5GS.
	MM.HoOutExe5gsToEpsFail.cause	Number of failed executions at the source gNB for handovers from EPS to 5GS.

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	MM.HoOut5gsToEpsFallbackPrepReq	Number of EPS fallback preparations requested by the source gNB for the outgoing handovers from 5GS to EPS.
	MM.HoOut5gsToEpsFallbackPrepSucc	Number of successful EPS fallback preparations received by the source gNB for the outgoing handovers from 5GS to EPS.
	MM.HoOut5gsToEpsFallbackPrepFail	Number of failed EPS fallback preparations received by the source gNB for the outgoing handovers from 5GS to EPS.
	MM.HoOutExe5gsToEpsFallbackSucc	Number of successful EPS fallback executions at the source gNB for handovers from 5GS to EPS.
	MM.HoOutExe5gsToEpsFallbackFail.cause	Number of failed EPS fallback executions at the source gNB for handovers from 5GS to EPS.
	MM.Ho5gsToEpsFallbackTimeMean	Mean time of EPS fallback whole handover during each granularity period.
	MM.HoExeHo5gsToEpsFallbackTimeMean	Mean time of EPS fallback handover executions during each granularity period.
Mobility Mgmt – RRC redirection measurement	MM.Redirection.5gsToEPSFallback	Number of RRC release for EPS fallback redirection.
Mobility Mgmt – Intra/Inter-frequency Handover related measurements	MM.HoExeIntraFreqReq	Number of outgoing intra-frequency handover executions requested by the source NRCellCU.
	MM.HoExeIntraFreqSucc	Number of successful intra-frequency handover executions received by the source NRCellCU.
	MM.HoExeInterFreqReq	Number of outgoing inter-frequency handover executions requested by the source NRCellCU.
	MM.HoExeInterFreqSecc	Number of successful inter-frequency handover executions received by the source NRCellCU.
Mobility Mgmt – Inter-gNB conditional handovers	MM.ChoPrepInterReq	Number of conditional handover preparations requested by the source gNB.
	MM.ChoPrepInterSucc	Number of successful conditional handover preparations received by the source NR cell CU.
	MM.ChoPrepInterFail.cause	Number of failed conditional handover preparations received by the source NR cell CU.
	MM.ChoResAlloInterReq	Number of conditional handover resource allocation requests received by the target NR cell CU.
	MM.ChoResAlloInterSucc	Number of successful conditional handover resource allocations at the target NR cell CU for the handover.
	MM.ChoResAlloInterFail.cause	Number of failed conditional handover resource allocations at the target NR cell CU for the handover.
	MM.ConfigInterReqCho	Number of outgoing conditional handover candidates requested by the source gNB.
	MM.ConfigInterReqChoUes	Number of UEs that have been configured with conditional handover by the source gNB.
	MM.ChoExeInterSucc	Number of successful conditional handover executions received by the source gNB.
	MM.ChoExeInterReq.TimeMean.SNSSAI	Mean time of inter-gNB conditional handover executions during each granularity period.
	MM.ChoExeInterReq.TimeMax.SNSSAI	Maximum time of inter-gNB conditional handover executions during each granularity period.
	MM.ChoPrepInterReqUes	Number of UEs for which conditional handover preparations were requested by the source gNB.

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Mobility Mgmt – Intra-gNB conditional handovers	MM.ChoPrepInterSuccUes	Number of UEs for which successful conditional handover preparations were received by the source NR cell CU.
	MM.ChoPrepInterFailUes.cause	Number of UEs for which conditional handover preparations failed, as received by the source NR cell CU.
	MM.ConfigIntraReqCho	Number of outgoing intra-gNB conditional handover candidates requested by the source NRCellCU.
	MM.ConfigIntraReqChoUes	Number of UEs that has been configured with conditional handover by the source cell.
	MM.ChoExeIntraSucc	Number of successful intra-gNB handover executions received by the source NRCellCU.
Mobility Mgmt – Inter-gNB DAPS handovers	MM.DapsHoPrepInterReq	Number of DAPS handover preparations requested by the source gNB.
	MM.DapsHoPrepInterSucc	Number of successful DAPS handover preparations received by the source NR cell CU.
	MM.DapsHoPrepInterFail.cause	Number of failed DAPS handover preparations received by the source NR cell CU.
	MM.DapsHoResAlloInterReq	Number of DAPS handover resource allocation requests received by the target NR cell CU.
	MM.DapsHoResAlloInterSucc	Number of successful DAPS handover resource allocations at the target NR cell CU for the handover.
	MM.DapsHoResAlloInterFail.cause	Number of failed DAPS handover resource allocations at the target NR cell CU for the handover.
	MM.DapsHoExeInterReq	Number of outgoing DAPS handover executions requested by the source gNB.
	MM.DapsHoExeInterSucc	Number of successful DAPS handover executions received by the source gNB.
	MM.DapsHoExeInterFail.UeCtxtRelCmd.cause	Number of failed DAPS handover executions.
Mobility Mgmt – Intra-gNB DAPS handovers	MM.DapsHoExeIntraReq	Number of outgoing intra-gNB DAPS handovers requested by the source NRCellCU.
	MM.DapsHoExeIntraSucc	Number of successful intra-gNB DAPS handovers received by the source NRCellCU.
TB related measurements	TB.TotNbrDlInitial	Total number of initial TBs transmitted on DL in a cell, excluding HARQ retransmissions.
	TB.IntialErrNbrDl	Number of initial faulty TBs transmitted on DL in a cell.
	TB.TotNbrDl.X	Total number of TBs transmitted on DL in a cell, including successful and failed TBs during initial transmission and HARQ retransmissions.
	TB.ErrToltalNbrDl.X	Number of total faulty TBs transmitted on DL in a cell, including all l transmitted faulty TBs of initial transmission and re-transmission.
	TB.ResidualErrNbrDl	Number of final faulty TBs transmitted on DL in a cell at last HARQ retransmissions.
	TB.TotNbrUlInit	Total number of initial TBs on UL in a cell.
	TB.ErrNbrUlInitial	Number of initial faulty TBs on UL in a cell.
	TB.TotNbrUl.X	Total number of TBs on UL in a cell, including successful and failed TBs during initial transmission and HARQ retransmission.
	TB.ErrToltalNbrUl.X	Number of total faulty TBs on UL in a cell, including all transmitted faulty TBs of initial and retransmission.
	TB.ResidualErrNbrUl	Number of final faulty TBs on UL in a cell.

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DRB related measurements	DRB.EstabAtt	Number of DRBs attempted to setup to support all requested QoS flows in the PDU sessions
	DRB.EstabSucc	Number of DRBs successfully setup to support all requested QoS flows in the PDU sessions
	DRB.RelActNbr	Number of abnormally released DRBs that were active at the time of release.
	DRB.SessionTime	Aggregated active session time for DRBs in a cell.
	DRB.InitialEstabAtt	Number of initial DRBs attempted to setup to support all requested QoS flows in the PDU sessions to be setup by the INITIAL CONTEXT SETUP REQUEST messages.
	DRB.InitialEstabSucc	Number of initial DRBs successfully setup to support all requested QoS flows in the PDU sessions to be setup by the INITIAL CONTEXT SETUP REQUEST messages.
	DRB.ResumeAtt	Number of DRBs attempted to be resumed.
	DRB.ResumeSucc	Number of DRBs successfully resumed.
	DRB.MeanEstabSucc	Mean number of DRBs that have been allocated
	DRB.MaxEstabSucc	Maximum number of DRBs that have been allocated.
	DRB.GTPUPathFailure	Number of DRB's prone to GTP-U Error Indication.
CQI related measurements	CARR.WBCQIDist.BinX.BinY.BinZ	Distribution of Wideband CQI (Channel Quality Indicator) reported by UEs in the cell.
MCS related measurements	CARR.PDSCHMCSDist.BinX.BinY.BinZ	Distribution of the MCS scheduled for PDSCH RB by NG-RAN
	CARR.PUSCHMCSDist.BinX.BinY.BinZ	Distribution of the MCS scheduled for PUSCH RB by NG-RAN.
	CARR.MUPDSCHMCSDist.BinX	Distribution of the MCS scheduled for PDSCH RB by NG-RAN in MU-MIMO scenario.
	CARR.MUPUSCHMCSDist.BinX	Distribution of the MCS scheduled for PUSCH RB by NG-RAN in MU-MIMO scenario.
QoS flow related measurements – release	QF.RelActNbr.QoS	Number of released QoS flows that were active at the time of release.
	QF.ReleaseAttNbr	Number of QoS flows attempted to release.
QoS flow related measurements – activity	QF.SessionTimeQoS.QoS	Aggregated active session time for QoS flow in a cell
	QF.SessionTimeUE	Aggregated active session time for UEs in a cell.
QoS flow related measurements – setup	QF.EstabAttNbr	Number of QoS flows attempted to setup.
	QF.EstabSuccNbr	Number of QoS flows successfully established.
	QF.EstabFailNbr.Cause	Number of QoS flows failed to setup.
	QF.InitialEstabAttNbr	Number of Initial QoS flows attempted to setup.
	QF.InitialEstabSuccNbr	Number of Initial QoS flows successfully established.
	QF.InitialEstabFailNbr.Cause	Number of Initial QoS flows failed to setup.
QoS flow related measurements – modification	QF.ModNbrAtt	Number of QoS flows attempted to modify.
	QF.ModNbrSucc	Number of QoS flows successfully modified.
	QF.ModNbrFail.cause	Number of QoS flows failed to modify.
RRC connection establishment related measurements	RRC.ConnEstabAtt.Cause	Number of RRC connection establishment attempts for each establishment cause.
	RRC.ConnEstabSucc.Cause	Number of successful RRC establishments for each establishment cause.
	RRC.ConnEstabFailCause	Number of failed RRC establishments.

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UE-associated logical NG-connection related measurements	UECNTX.ConnEstabAtt.Cause	Number of attempted UE-associated logical NG-connection establishments.
	UECNTX.ConnEstabSucc.Cause	Number of successful UE-associated logical NG-connection establishments.
RRC connection Re-establishment	RRC.ReEstabAtt	Number of RRC connection re-establishment attempts.
	RRC.ReEstabSuccWithUeContext	Number of successful RRC connection re-establishment when UE context can be retrieved.
	RRC.ReEstabSuccWithoutUeContext	Number of successful RRC connection re-establishment when UE context can not be retrieved.
	RRC.ReEstabFallbackToSetupAtt	Number of RRC connection re-establishment attempts where no UE context could be retrieved.
RRC connection resuming	RRC.ResumeAtt.cause	Number of RRC connection resuming attempts.
	RRC.ResumeSucc.cause	Number of successful RRC connection resuming.
	RRC.ResumeSuccByFallback.cause	Number of successful RRC connection resuming by fallback to RRC connection establishment.
	RRC.ResumeFollowedbyNetworkRelease	Number of RRC connection resuming followed by network release.
	RRC.ResumeFollowedbySuspension	Number of RRC connection resuming followed by network suspension.
	RRC.ResumeFallbackToSetupAtt.cause	Number of RRC connection resuming attempts where no UE context could be retrieved.
Power, Energy and Environment (PEE) measurements – PNF power consumption	PEE.AvgPower	Average power consumed over the measurement period.
	PEE.MinPower	Minimum power consumed during the measurement period
	PEE.MaxPower	Maximum power consumed during the measurement period.
PEE measurements – PNF energy consumption	PEE.Energy	Energy consumed.
PEE measurements – PNF temperature	PEE.AvgTemperature	Average temperature over the measurement period.
	PEE.MinTemperature	Minimum temperature over the measurement period.
	PEE.MaxTemperature	Maximum temperature over the measurement period.
PEE measurements – PNF voltage	PEE.Voltage	Voltage.
PEE measurements – PNF current	PEE.Current	Current.
PEE measurements – PNF humidity	PEE.Humidity	Percentage of humidity during the measurement period.
Received Random Access Preambles	RACH.PreambleDedCell / RACH.PreambleACell / RACH.PreambleBCell	Average number of RACH preambles received in a cell.
	RACH.PreambleDed.Ssb / RACH.PreambleA.Ssb / RACH.PreambleB.Ssb	Average number of RACH preambles received in a cell per SSB.
	RACH.PreambleDist.Bin	Distribution of the number of RACH preambles sent by the UE when successfully accessing the network.
	RACH.AccessDelayDist.Bin	Estimate of the distribution of the RACH access delay.

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Intra-NRCell SSB Beam switch measurements	MR.IntraCellSSBSwitchReq	Number of outgoing intra-NRCell SSB Beam switch executions requested by the source SSB Beam.
	MR.IntrCellSuccSSBSwitch	Number of successful intra-NRcell SSB Beam switch executions received by the source SSB Beam.
RSRP measurement	L1M.SS-RSRP.Bin	Distribution of SS-RSRP per SSB in the cell.
	L1M.SS-RSRPNrNbr.SSBIndex.Bin	Distribution of SS-RSRP per SSB of a neighbour cell.
	L1M.RSRPEutraNbr.Bin	Distribution of RSRP per neighbour E-UTRA cell.
Number of active UEs	DRB.MeanActiveUeDl_Filter	Mean number of active DRBs for UEs in an NRCellDU in DL.
	DRB.MaxActiveUeDl_Filter	Maximum number of active DRBs for UEs in an NRCellDU in DL.
	DRB.MeanActiveUeUl_Filter	Mean number of active DRBs for UEs in an NRCellDU in UL.
	DRB.MaxActiveUeUl_Filter	Maximum number of active DRBs for UEs in an NRCellDU in UL.
5QI 1 QoS Flow Duration monitoring	5QI1QoSflow.Rel.Average.NormCallDuration	Average value of normally released call duration.
	5QI1QoSflow.Rel.Average.AbnormCallDuration	Average value of abnormally released call duration.
	5QI1QoSflow.Rel.NormCallDurationBinX	Histogram result of the samples related to normally released call duration collected during measurement period duration.
	5QI1QoSflow.Rel.AbnormCallDurationBinX	Histogram result of the samples related to abnormally released call duration collected during measurement period duration.
Measurements related to MRO	HO.IntraSys.TooEarly / HO.IntraSys.TooLate / HO.IntraSys.ToWrongCell	Number of handover failure events related to MRO detected during the intra-system mobility within 5GS.
	HO.InterSys.TooEarly / HO.InterSys.TooLate	Number of handover failure events delated to MRO detected during the inter-system mobility between NG-RAN and E-UTRAN.
	HO.InterSys.Unnecessary	Number of unnecessary handover events detected during the inter-system mobility from NG-RAN to E-UTRAN.
	HO.InterSys.PingPong	Number of handover ping-pong events detected during the inter-system mobility between NG-RAN and E-UTRAN.
	HO.IntraSys.bTooEarly.NCI / HO.IntraSys.bTooLate.NCI / HO.IntraSys.bToWrongCell.NCI	Number of handover failure events per beam-cell pair related to MRO detected during the intra-system mobility within 5GS.
	HO.InterSys.bTooLate.ECGI	Number of handover failure events per beam-cell pair related to MRO detected during the inter-system mobility from 5GS to EPS.
	HO.InterSys.bUnnecessary.ECGI	Number of unnecessary handover events per beam-cell pair detected during the inter-system mobility from 5GS to EPS.
	HO.InterSys.bPingPong.NCI	Number of handover ping-pong events per beam-cell pair detected during the inter-system mobility from 5GS to EPS.
PHR measurement	L1M.PHR1.BinX	Histogram of Type 1 power headroom measurements.

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Paging measurement	PAG.ReceivedNbrCnInitiated	Number of CN Initiated paging records received by the gNB-CU.
	PAG.ReceivedNbrRanIntiated	Number of NR RAN Initiated paging records received by the gNB-CU.
	PAG.ReceivedNbr.	Number of paging records received by gNB-DU.
	PAG.DiscardedNbrCnInitiated	Number of CN Initiated paging records discarded at the gNB-CU.
	PAG.DiscardedNbrRanInitiated	Number of NG-RAN Initiated paging records discarded at the gNB-CU.
	PAG.DiscardedNbr	Number of paging records discarded at gNB-DU in cells.
SSB beam related measurement	L1M.SSBBeamRelatedUeNbr	Mean number of UE related the SSB beam index.
Transmit power utilization measurements	CARR.MaxTxPwr	Maximum carrier transmit power in the measurement granularity interval.
	CARR.MeanTxPwr	Mean carrier transmit power in the measurement granularity interval.
MU-MIMO related measurements	CARR.MUPDSCHRB.BINX	Distribution of the scheduled PDSCH RBs per MU-MIMO layer.
	CARR.MUPUSCHRB.BINX	Distribution of the scheduled PUSCH RBs per MU-MIMO layer.
	RRU.MaxLayerDlMimo	Time-domain average maximum scheduled layer number for PDSCH.
	RRU.MaxLayerUlMimo	Time-domain average maximum scheduled layer number for PUSCH.
	CARR.AverageLayersDl	Average value of allocated MIMO layers on DL per PRB per cell within the measurement period.
	CARR.AverageLayersUl	Average value of allocated MIMO layers on UL per PRB per cell within the measurement period.
RSRQ measurement	MR.NRScSSRSRQ.BinX	Distribution of SS-RSRQ received by gNB from UEs in the cell.
	MR.SS-RSRQPerSSB.Bin	Distribution of SS-RSRQ per SSB received by the gNB of a serving cell.
	MR.SS-RSRQ.SSBIndex.Bin	Distribution of SS-RSRQ per SSB received by the gNB of a neighbour cell.
SINR measurement	MR.NRScSSSINR.BinX	Distribution of SS-SINR received by gNB from UEs in the cell.
	MR.SS-SINRPerSSB.Bin	Distribution of SS-SINR per SSB received by the gNB of a serving cell.
	MR.SS-SINR.SSBIndex.Bin	Distribution of SS-SINR per SSB received by the gNB of a neighbour cell.
Timing Advance	L1M. ATADist.Bin	distribution of the Absolute Timing Advance values transmitted by the gNB to UEs in the cell.
Incoming GTP Data Packet Loss in gNB over N3	GTP.InDataPktPacketLossN3gNB	Number of GTP data packets which are not successfully received at gNB over N3.

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TABLE 4-2: MEASUREMENTS FOR NON-SPLIT GNB.

Group	Measure	Description
PDCP Data Volume measurements - DL	DRB.PdcpSduVolumeDL_Filter	Data Volume in DL delivered to PDCP layer.
	DRB.PdcpSduVolumeX2DL_Filter	Data Volume in DL delivered on X2 interface in DC-scenarios.
	DRB.PdcpSduVolumeXnDL_Filter	Data Volume in DL delivered on Xn interface.
PDCP Data Volume measurements - UL	DRB.PdcpSduVolumeUL_Filter	Data Volume in UL delivered from PDCP layer to higher layers.
	DRB.PdcpSduVolumeX2UL_Filter	Data Volume in UL delivered on X2 interface in NSA scenarios.
	DRB.PdcpSduVolumeXnUL_Filter	Data Volume in UL delivered on Xn interface in SA scenarios.
Packet Success Rate	DRB.PacketSuccessRateUlgNBUu	Fraction of PDCP SDU packets which are successfully received at gNB.

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TABLE 4-3: MEASUREMENTS FOR SPLIT GNB.

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Group	Measure	Description
Packet Loss Rate	DRB.PacketLossRateUl	Fraction of UL PDCP SDU packets which are not successfully received at gNB-CU-UP, including any packet losses in the air interface, in the gNB-CU and on the F1-U interface..
	DRB.F1UpacketLossRateUl	Fraction of UL PDCP SDU packets which are not successfully received at gNB-CU-UP on the F1-U interface.
	DRB.F1UpacketLossRateDl	Fraction of DL PDCP SDU packets which are not successfully received at gNB-CU-UP on the F1-U interface.
Packet Drop Rate	DRB.PdcpPacketDropRateDl	Fraction of PDCP SDU packets which are dropped on DL in the gNB-CU-UP. Only user-plane traffic (DTCH) is considered.
	DRB.RlcPacketDropRateDl	Fraction of RLC SDU packets which are dropped on DL in the gNB-DU. Only user-plane traffic (DTCH) is considered.
Packet Delay	DRB.PdcpSduDelayDl_Filter	Average PDCP SDU delay on DL within the gNB-CU-UP, for all PDCP packets.
	DRB.PdcpF1DelayDl_Filter	Average GTP packet delay DL on the F1-U interface.
	DRB.RlcSduDelayDl	Average RLC SDU delay on DL within the gNB-DU, for initial transmission of all RLC packets.
	DRB.PdcpSduDelayDlDist.Bin_Filter	Distribution of PDCP SDU delay on DL within the gNB-CU-UP, for all PDCP packets.
	DRB.GtpF1DelayDlDist.Bin_Filter	Distribution of GTP packet delay DL on the F1-U interface.
	DRB.RlcSduDelayDlDist.Bin_Filter	Distribution of RLC SDU delay on DL within the gNB-DU, for initial transmission of all RLC packets.
IP Latency measurements	DRB.RlcSduLatencyDl	Average IP Latency in DL within the gNB-DU, when there is no other prior data to be transmitted to the same UE in the gNB-DU.
	DRB.RlcSduLatencyDlDist.bin	Distribution of IP Latency in DL within the gNB-DU, when there is no other prior data to be transmitted to the same UE in the gNB-DU.
UE Context Release	UECNTX.RelReq.Cause	Number of UE CONTEXT RELEASE initiated by gNB-DU for each release cause.
	UECNTX.RelCmd.Cause	number of UE CONTEXT RELEASE initiated by gNB-CU for each release cause.
PDCP Data Volume measurements - PDCP PDU	QosFlow.PdcpPduVolumeDL_Filter	Data Volume in DL delivered from GNB-CU to GNB-DU.
	QosFlow.PdcpPduVolumeUl_Filter	Data Volume in UL delivered from GNB-DU to GNB-CU.
PDCP Data Volume measurements - PDCP SDU	QosFlow.PdcpSduVolumeDl_Filter	Data Volume in DL delivered to PDCP layer.
	QosFlow.PdcpSduVolumeUL_Filter	Data Volume in UL delivered from PDCP layer to SDAP layer or UPF.
	DRB.F1uPdcpSduVolumeDL_Filter	Data Volume in DL delivered from gNB-CU-UP to gNB-DU (F1-U interface), to external gNB-CU-UP (Xn-U interface) and to external eNB (X2-Uinterface).

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	DRB.F1uPdcpSduVolumeUL_Filter	Data Volume in UL delivered from gNB-CU-UP to gNB-DU (F1-U interface), to external gNB-CU-UP (Xn-U interface) and to external eNB (X2-Uinterface).
Handovers measurements – Intra-gNB	MM.HoPrepIntraReq	Number of outgoing intra-gNB legacy handover preparations requested by the source NRCellCU.
	MM.HoPrepIntraSucc	Number of successful intra-gNB legacy handover preparations received by the source NRCellCU.
	MM.ChoPrepIntraReq	Number of outgoing intra-gNB conditional handover preparations requested by the source NRCellCU.
	MM.ChoPrepIntraSucc	Number of successful intra-gNB conditional handover preparations received by the source NRCellCU.
	MM.DapsHoPrepIntraReq	Number of outgoing intra-gNB DAPS handover preparations requested by the source NRCellCU.
	MM.DapsHoPrepIntraSucc	Number of successful intra-gNB DAPS handover preparations received by the source NRCellCU.
	MM.ChoPrepIntraReqUes	Number of UEs for which outgoing intra-gNB conditional handover preparations are requested by the source NRCellCU.
	MM.ChoPrepIntraSuccUes	Number of UEs for which intra-gNB conditional handover preparations received by the source NRCellCU are successful.

4.3. Data structures available @5GC

For some specific situations or functionalities, it may be interesting to collect data from entities of the 5GC. To reach that information, there exists two possible alternatives: we can obtain the data from the OAM, or via the subscription to the exposure events that each entity of the 5GC executes. The list of all performance measurements of the 5GC entities that can be executed is presented in [13], and the information that can be retrieved from the exposure events for each block of the 5GC is listed in [7], with their procedure detailed in [14].

As the first deployment option explained in section 4.1 is not connected to the 5GC, the only possible way of obtaining data from the 5GC entities is through the OAM.

In case of being untrustworthy and wanting to collect data from entities of the 5GC via exposure events, it is mandatory to subscribe to them through the NEF, as it is explained before. The procedure to achieve it is detailed in [14].

4.4. Additional information

Despite providing such a large amount of data, in this section is proposed extra information which can be useful at the time of developing a gNB DT and it is not considered to be exposed in the standards. Hence, the decision of exposing it and how to do it resides in each particular vendor:

- Additional information related to the physical radio layer, e.g. the channel band, the bandwidth, the subcarrier spacing, duplex scheme, modulation, scheduling scheme.

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- UE capability information.
- Type of gNB, in case the vendor has developed more than one.
- Information related to the latency in the response of the servers holding the applications.
- KPI derating factor.

5. Minimum data required for a gNB DT

Obviously, not all data is necessary for all applications. In other words, the data that is required to construct the DT depends on the function that is sought. As an example, if one is interested in predicting periodic changes in energy consumption, it might be thought that the only measurement needed to develop the DT is the one which extracts the value of the energy consumed (named PEE.Energy).

In the following subsections, it is provided some examples of applications from the literature that can be deployed, and the minimum data required for constructing the DT is presented.

5.1. Required data for vrAIN

vrAIN is a controller of dynamic resources for virtualization of RANs, presented in [15], which helps to enhance the performance of the network, saving computational capacity, meeting better QoS and improving the throughput. The input of this algorithm is information referred to the Signal to Noise Ratio (SNR) and arrival data.

One can find these information using the following measurements: MR.NRScSSSINR provides the distribution of SNR received by the gNB; and, to obtain the arrival data, for example, DRB.UEThpDl and DRB.UEThpUl can be used, which provide the average UE throughput in downlink and uplink, respectively.

5.2. Required data for DeepCog

In [16], DeepCog is presented. It is a novel data analytic tool which predicts traffic demands of network slices and reallocates the resources of the network, taking into account the operator's desires. To achieve its objective, it needs some input data, which is (as it is explained in the document) the demand of the network in terms of signal quality, occupied resource blocks or bytes of traffic, among others.

One option is to obtain this kind of information from RRU.PrbUsedDl and RRU.PrbUsedUl measurements, which provides the total number of physical resource blocks (PRBs) on average available in downlink or uplink, respectively. These particular measurements can be divided into different counters depending on the QoS class.

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